QUANTIFYING THE SPATIAL AND TEMPORAL VARIATION OF THE AIR QUALITY HEALTH INDEX IN HALIFAX, NOVA SCOTIA

by

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ABSTRACT

The AQHI, currently used by the Canadian government, is a multi-pollutant public health information tool that is based upon extensive Canadian epidemiological evidence. As the AQHI is a relatively new metric, there is little published information about the accuracy, and behaviour of this metric both spatially and temporally. The goal of this work was to provide more information to the scientific community on the spatial and temporal behaviour of the AQHI in the Halifax, Nova Scotia region. Sampling was conducted in both the winter and summer of 2009, at 50 sites distributed around the city and at the central NAPS site in downtown Halifax. Statistical analysis was conducted using daily calculated AQHI values. AQHI values in the region were predominantly in the 1 to 3 range on the AQHI scale which corresponds to very good air quality. The Government reported AQHI was found to be significantly different from the 50 sample site s AQHI values for both summer and winter ($P=<0.001$ for both seasons). The Government reported AQHI was significantly higher ($P=0.05$) than the AQHI calculated for the 50 sampling sites. Analysis identified that more than 50% of the daily AQHI index values were reported differently than the local sites, most commonly over predicted by one AQHI index point. Analysis also indicated a temporal trend of disagreement between the reported and sampled AQHI values. It was observed that during periods when the AQHI was higher, there was greater disagreement between that reported and the sample site AQHI value. This finding raises some concern regarding the behaviour of the AQHI in both larger cities and over the next decade as Halifax increases in size. The miss-reporting of AQHI values also raises some concern for epidemiological work, if the AQHI is used as an exposure metric it could over estimate exposure to air pollution. However, the AQHI is a useful scientific measure having a number of advantages, first it is a multi pollutant measure based on sound epidemiological evidence linking a mixture of three major air pollutant metrics to health effects and second that it has been distilled into a form that is readily understood by the public. This project has been successful in providing more information to the scientific community on the spatial and temporal variation of the AQHI in the Halifax region. It has been able to identify both seasonal and temporal variation, reinforced the understanding of pollutant behaviour and has begun to provide information on the behaviour of the AQHI on small urban scales and provide valuable information for both researchers and policy makers on the AQHI from a public health context.

LIST OF ABBREVIATIONS USED

ANOVA………………………….......……………………………………… Analysis of variance

AQHI………………………………… ……………………………… Air quality health index

CO……………………………..…………………………………………... Carbon monoxide

CO_2…………………………………………………………………………... Carbon dioxide

COPD…………………………….…………………… Chronic obstructive pulmonary disease

DEM…………………………… …………………………………….. Digital elevation map

FRM…………………………… ………………………………… Federal reference method

GIS……………………………………...…………………... Geographic information system

GLO……………………….....…………………………………………… Ground level ozone

HRM…...…………………….....………………………………. Halifax Region Municipality

KW-Dun Kruskal-Wallis……………….. ANOVA and Dunn's method for multiple comparisons

LUR……………………….……………………………………………….. Land use regression

NAPS……………………….....…………………………… National air pollution surveillance

NO_x…………………….....…………………………………………... Oxides of nitrogen

NPRI……………………………………………………… National pollution release inventory

O_3…………………………………………………...…………………………….. Ozone

PAN……………………....………………………………….…………… Polyacrylonitrile nitrate

PM…………………..………………..…………….………………………. Particulate matter

PM_{10}……………….…… Particulate matter with an aerodynamic diameter smaller than 10 micron

$PM_{2.5}$……………...….. Particulate matter with an aerodynamic diameter smaller than 2.5 micron

PM_{UF}………………….….. Particulate matter with an aerodynamic diameter smaller than 1 micron

HIAQS…………….……………………………… Residential indoor air quality exposure study

RMA……………………………..………..……………………………….. Reduced major axis

SO_x……………………………….…...…………….…………………….. Oxides of sufur

SOP……………………………….……………………… Standard operating procedures

TEA…………………………………..…………………………………... Tri-ethanolmine

VOC………………………………………………………………… Volatile organic compounds

US EPA……………………………...……….. United States Environmental Protection Agency

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Thank you everyone!

CHAPTER 1.0 INTRODUCTION

1.1 AIR POLLUTION AND HEALTH

Epidemiological studies have demonstrated relationships between mixtures of toxic gases, inhalable particles and their components and various negative health outcomes both for acute and chronic exposures. Negative health outcomes range from eye irritation to death, but most commonly include asthma, chronic obstructive pulmonary disease (COPD), allergic sensitization, various forms of cardiovascular disease, and lung cancer particularly for children and the elderly (1-6). Infants exposed in utero also have been identified as being particularly at risk for adverse outcomes including low birth weight and small for gestational age births demonstrating the alternate pathways of interaction (4,7).

Historical evidence also demonstrates the negative effects of air pollution with several cases of mass death resulting from high air pollution levels in the past 100 years. There are two major forms of air pollution events which have been responsible for the large incidences over that time period. First, the sulfurous and soot rich black fog of Meuse Valley, Belgium in 1930 and London, UK in the 50's and 60's. This particular and distinctive form of smog is currently appearing in in developing nations as coal and sulfur rich fuels are gaining prevalence (8). Secondly, the NO_x rich photochemical smog of Los Angeles and other modern cites, starting in the 40's. Currently in the western world, air pollution is different in character from these famous examples as the chemical and physical make has changed as a result of changing fuel sources and emission sources (9).

Studies have confirmed relationships between the components of air pollution and mortality through large cohort and time series studies, (3,5,10) as well as establishing associations between air pollution, heat wave events and other short term events for negative health outcomes (11,12). While the various studies demonstrating the links between air pollution and the respiratory and cardiovascular outcomes are of the main interest for air pollution research, there has been growing interest in ultra fine particles, which is a size fraction of smaller than 100 nm in aerodynamic cross-section, and their effects on health; (particularly related to children and individuals during exercise) as a result of their ability to enter the blood stream and lymphatic system (13-16).

There are both natural and anthropogenic sources of air pollution which contribute to the local and long-range total air pollution burden of which the composition may be either primary or secondary in origin (17). For example, forest fires and industrial emissions are long range natural and anthropogenic sources of air pollution respectively, while biological products - volatile chemical emissions from plants, and car emissions may have a stronger local influence (18). Depending upon meteorological conditions, as well as season and diurnal cycles, either strong local sources or upwind air pollution sources can dominate at any given receptor. For example, local anthropogenic activities such as car emissions can strongly influence urban air quality, while in rural Annapolis Valley anthropogenic wood smoke dominates the air pollution burden during the winter (19). However in both regions local sources can be over-whelmed by anthropogenic smog events being carried in via the prevailing winds from the Windsor – Québec corridor and north-eastern USA or long range wood smoke from natural forest fires ranging across northern Canada (20). Air pollution is recognized as an important determinant of health in both the developed and developing worlds but the complex relationship between source, fine respirable particle components, spatio-temporal variation and health is still not fully understood (2).

As previously noted air pollution is a complex mixture of various chemicals and particulate matter that can exist in all three of the common phases. This mixture can include gases including thousands of volatile organic compounds (VOCs), oxides of sulfur (SO_x), ground-level ozone (GLO) carbon monoxide (CO), carbon dioxide (CO_2), oxides of nitrogen (NO_x) and aldehydes such as formaldehyde and acrolein (15). Particulates can be made up of various different substances including both natural inorganic and organic particles like dirt or pollen and man-made particles from engine combustion, vehicle brake wear and mechanical tools such as metal grinders or power drills all of which can have different shapes and chemical compositions(15).

Atmospheric particulate matter (PM) is commonly divided into three size fractions based on health risks and level of concern. These size fractions include those particles with a median aerodynamic diameter less than 10 µm (PM_{10}), less than 2.5 µm ($PM_{2.5}$) and ultrafine particles (PM_{UF}) less than 0.1 µm (12). Generally speaking, $PM_{2.5}$ to PM_{UF}, known as fine particles, result from high energy processes followed by agglomeration and coagulation, PM_{10} to $PM_{2.5}$, known as course particles, generally results from low energy natural emissions e.g. sea salt and wind suspended fugitive dust (9). The three PM size cut points are identified by the level of penetration into the lung, Coarse particles are restricted to the upper airway while $PM_{2.5}$ to PM_{UF} can penetrate into the lungs and PM_{UF} can pass through the cell interface and enter the bloodstream and lymphatic system (15).

Inhaled PM has been associated with causing atherosclerosis, oxidative stress, inflammation and cancer (5,21,22). There is still some uncertainty about which characteristics of the many components of air pollution can be linked to adverse health effects. However, many of the gas components are known carcinogens and particulates have been linked to cardiovascular and respiratory disease. The conglomerated components of these particles may cause harm as a result of their individual or total composition, acting in synergy or physical morphology, e.g. asbestos and silicosis both of which are grave health risks because of their morphology (23-25).

There are recognized difficulties in assigning exposure to the population at large and many studies have relied on data from central government monitoring sites, such as the Environment Canada National Air Pollution Surveillance (NAPS) sites, which are suitable for large cohorts distributed over large areas (26,27). However, the distribution of the Federal Reference sites, lack the spatial resolution for examining the intra-urban variability of air pollution which is mostly driven by local sources and the road network. Recently many studies have begun to link the exposure of pollutants to increased rates of adverse health outcomes using spatial factors and several different innovative modelling methods which has provided another tool for epidemiologists to understand how our air environment affects human health (28).

Several modelling methodologies have been used to attempt to address the lack of spatial resolution (29). Common methods used include: Geographic Information System (GIS) analysis using various statistical interpolation, and dispersion modelling methods and more recently regression based models (30,31). In addition, metrics such as distance to roads, road volume and land use have also been explored as predictors of air pollution concentrations in the spatial domain of interest (29). Molitor et al. (2007) suggests that the new developed regression models are generally more accurate then the various surface interpolation and dispersion modelling efforts but that there are still many difficulties in developing good prediction models including the difficulty in developing accurate GIS databases. Two other difficulties in developing strong models is the lack of multi seasonal data for testing and the focus on using NO_2 as a proxy for vehicle traffic which affects the fit of the models to other pollutants (29,31).

1.2 THE AIR QUALITY HEALTH INDEX

The recently developed Environment Canada Air Quality Health Index (AQHI) is a no-threshold numeric scale that is designed to reflect the amount of multi-pollutant air pollution and the health significance of the concentration based on epidemiological studies of the effects of the various pollutants of Canadian data (32). The AQHI is a newly developed tool for assessing the severity of air pollution and as such little work as currently been conducted using it as an evaluation metric. However it can be used as metric for scientific research as it reports both air pollution levels and is also a public information tool.

The AQHI was developed to reflect new epidemiological understanding of Canadian data reflecting the interaction effect of different air pollutants with each other and the impact on human health. In addition, its formulation takes into account that, at a population level, there is no safe level of air pollution (32). It is replacing the Air Quality Index, in a region by region basis, which forecast the maximum level of various pollutants and assigned them one of four risk categories which were then used to calculate overall air quality (33). The AQHI is also a risk communication tool designed to inform the public about the quality of air in their region and the possible health risks associated with the air quality. The AQHI provides the public with the means to self calibrate against the current index value so that each person can decide at what level they feel they are at increased risk and to make better informed choices with regards to their outdoor activity. The AQHI is currently being used by several provinces across Canada and being presented on the Weather Network, Environment Canada weather website and Health Canada website.

Nationally, the AQHI is calculated using information from the National Air Pollution Surveillance (NAPS) system and is calculated hourly using a three running mean pollutant concentrations for NO_2, GLO and $PM_{2.5}$. Which were identified as having the greatest effect on human health but also for their interactive effect and representativeness of other pollutants (32). One of the challenges for the AQHI is the limited number of sites used for calculating the values and the limited spatial distribution of the sites. Locally (Halifax region) the AQHI is calculated using two NAPS sites, one located in central Halifax and a second at Lake Major in Dartmouth. The limited number of sites forces an assumption of even distribution of air pollution across a region and it is currently unknown how accurate this assumption is. The paucity of monitoring sites are driven by several factors including regional representation, the cost of equipment and having access to a secure site with electrical power in which to permanently place the equipment. This creates two challenges for the sampling network, first, the location of the sampling site needs to representative for the local air-shed and second the general low density of sites makes it difficult to fully understand the spatial-gradients that exist across urban scales. The goals of this work were planned to help clarify some of these issues and develop a better understanding of the effectiveness of the AQHI for describing local conditions and to assess the accuracy of the AQHI for community exposure.

1.3 Spatial and temporal modelling of air pollution

There is increasing interest in better understanding the relationship between the spatial and temporal distribution of air pollution and human health, particularly in urban and suburban areas which contain both large concentrations of people and large anthropogenic sources of air pollution (34-39). Historically, studies have focused on variation of air pollution composition and exposure across large areas, such as continental USA (40) or interaction between air pollution and short term stressors on particular at risk groups (11,41).

Recently, research has linked chronic exposure to ambient air pollution on smaller intra-urban scales with both negative cardiac and respiratory health outcomes (21). Also, recent studies have emphasized the negative impacts from locally derived traffic-related pollutants on respiratory health suggesting that variability within small urban areas related to land-use and socio economic status can have significant health effects (42,43). Intra-urban modelling has also begun to explore ultrafine particle concentration gradients along road networks and the risks for children and active persons often using NO_2 as a surrogate for ultra fine particles (44).

Spatial modelling of air pollution has been a challenging topic for epidemiological studies with researchers having to make assumptions for levels of exposure to pollutants for a population based on single site monitoring (5,26). Traditionally there have been two general approaches to air pollution mapping in an attempt to gain more accurate information: spatial interpolation and dispersion modelling each of which has strengths and weaknesses as is more applicable to specific types of research (45,46).

Spatial interpolation is dependent on statistical methods to either model a pollutant predictive surface from the measured pollutant levels or to use a deterministic approach to expand on the measured values to better understand the spatial distribution of pollutants. With the advent of GIS many tools have been developed to assist with this methodology. Interpolation can be further divided into global interpolation methods that use the full data set to create pollutant surface and local interpolation methods such as the commonly used kriging and spline interpolation methods which use a local subset of the data set to estimate pollutant levels in more spatially restricted area. Spatial interpolation has particular uses in large scale pollution contour mapping, with large centralized sources of pollutants (22,46).

Dispersion modelling takes a different approach to pollutant modelling, instead of taking point samples through a region and mapping the resulting levels, the emission of pollutants are catalogued and modeled through specialized programs (46,47). Dispersion modelling has several strengths including being able to be adapted for any area where pollutants sources are available, and inclusion of environmental factors, it is particularly effective for single point sources on small scales (e.g. smoke stacks) and has been adapted for line sources such as roads, however it requires very specific information about pollutant sources which are available for point sources such as smoke stacks from the National Pollutant Release Inventory (NPRI) but are often out of date. In highly urbanized areas there is the added challenge of incorporating multiple linear sources such as roads. Dispersion modelling also is generally unable to incorporate small scale emissions such as chimneys and barbecues because there is no emissions database for these small and intermittent sources (46,48).

In an attempt to address the weaknesses of the different modelling methods and to gain as much accurate information from available data, the Briggs group of Imperial College in London, United Kingdom, developed a regression based modelling technique using GIS. This method, named Land Use Regression (LUR) takes a different approach to air pollution modelling from either of the two previously methods but has more in common with spatial interpolation. The original method used least squares regression based on a combination of pollutant monitoring data and environmental information to produce a predictive surface layer (46). LUR is dependent on large and accurate GIS databases and is specific to the location for which it is developed, differences in traffic composition, regional social structures, geography and age of city development make generally not possible to move a LUR from one city to the next. It does however address the smoothing nature of interpolation allowing for accurate and fine scale prediction.

Spatial and temporal modeling can feed into a second type of modeling which is fate and transport modeling which is designed to better understand how the pollutants of interest move through the environment and impact on human health. This type of model is very important for making links between sources and receptors who's health is of primary interest (49).

1.4 DATA AVAILABLE

The data which was used for this thesis is from the Halifax Indoor Air Quality Exposure Study (HIAQS) which was undertaken by Health Canada in collaboration with the Atlantic RURAL Centre, Department of Community Health and Epidemiology. This study was a comprehensive analysis of both indoor and outdoor air quality taken at various locations randomly selected across the Halifax landscape in the winter and summer of 2009. These data provided the opportunity to calculate local AQHI values which could then be compared to the reported AQHI values and values calculated from the local NAPS location in downtown Halifax as well as Global Positioning System (GPS) coordinates for the sample locations.

The Residential Indoor Air Quality Exposure Study is one of a suite of studies supported by Health Canada in their desire to update the *Exposure Guidelines for Residential Indoor Air Quality* originally published in 1987. Through the Clean Air Agenda, Health Canada committed to conducting exposure studies to provide information on air quality across Canada. As a Canada-wide study would be unfeasible Health Canada has collaborated with provincial partners and academic institutions in Quebec, Saskatchewan and Nova Scotia to investigate exposure levels and sources which attribute to air quality in residences

1.5 BACKGROUND LITERATURE

As a newly designed metric there is very little published research in the scientific data base. At the time of writing the available published research around the AQHI includes the founding paper of the metric by Stieb et al 2008 in which the authors describe the epidemiological background to the AQHI, the rational for using the AQHI and presents several integrations of the AQHI calculation formula including two versions for warm and cool air temperature (seasonal) conditions.

The remainder of the literature related directly to the AQHI is three abstracts from presentations at scientific conferences. The earliest presentation is a smog case study in Quebec in 2008 conducted by Environment Canada and presented at the US Environmental protection Agency's (EPA) National Air Quality Conference in Dallas, Texas by Rousseau in 2009 (33). In this presentation the author explores the effect of a heavy smog episode on the region AQHI and how it responds to changes in pollutant mixture changes.

The remaining two abstracts are from posters presented at the American Journal of Critical Care Medicine Annual Congress in 2011. These two abstracts by Atenafu et all (2011)(50) and Licskal et al (2011)(51) were presented in the Asthma Epidemiology section of the conference and explore the impact of air quality on asthma health using the AQHI as a metric for exposure and exploring the usefulness of integrating the AQHI into asthma action plans.

As previously stated, there is very little published research available on the AQHI metric even though it has become a central part of Canada's air quality monitoring program which identifies the need for research to improved understanding the behaviour of this metric, exploring it's behaviour in real world conditions and testing its usefulness as a research tool.

1.6 AIMS

The over-arching goal of this work is to better understand those factors which contribute to variations in AQHI measurements over space and time with relation to the Environment Canada reported AQHI. This will aid in the validation of the AQHI as a valuable public health risk communication tool for both the scientific community and regulatory bodies. As stated previously, there has been little work studying local AQHI values in comparison with values calculated from the central sites which are used to present the information to the public, as well seasonal variation is not well understood. To address these challenges four objectives were identified:

i. developing unique AQHI values for each home during the study
ii. assessing the seasonal and inter-site variation in AQHI values calculated for each study site and comparing the central site and NAPS values to the individual calculated values and the averaged site values to the central site value
iii. assessing the spatiotemporal variation of individual pollutants with respect to AQHI values and the central site and NAPS monitoring system
iv. to develop spatial interpolations of the AQHI pollutants to better understand the geographic distribution of the pollutants

The four objectives have been identified based around the available data and expertise available. They were identified as an effective way to address areas of weakness in our understanding of air quality, its spatiotemporal variation over urban spatial scales and the effectiveness of Canada's air quality population risk assessment tool the AQHI methods. Through conversations with Health Canada and Environment Canada, they have been refined to add value to research currently underway and to supply information needed for better understanding of the behaviour of AQHI on the local scales and to provide information needed for improvements in the regulation of air pollution.

CHAPTER 2.0 METHODS

The methods will be divided into two broad sections, first the Halifax Indoor Air Quality Study (HIAQS) will be covered, explaining the sampling design, sampling methods, data collection and analysis which, in turn, provided the data for the analysis contained in this thesis. It is important to understand how the data has been collected in order in understand both the strengths and weaknesses of the data set being analyzed. This will be followed by the methods used in the current work, covering data analysis, statistical methods and GIS mapping efforts.

2.1 HALIFAX INDOOR AIR QUALITY STUDY

In Halifax, NS data were collected during the winter and summer of 2009 in fifty residences spatially distributed across the urban core of the HRM (Figure. 1). The participants were recruited by Qualitative Field Services Corporate Research Associates Inc., who applied random digit dialling methods to select a stratified sample of homes using a formalized recruitment protocol that integrated inclusion and exclusion criteria. This enabled identification of sufficient residences to complete the required sampling first for the winter then to replace dropouts after the first phase. The participant houses were age stratified into five categories: 1945 and before, 1946-1960, 1961-1980, 1981-2000, and 2001-2008 (the last was oversampled so to include sufficient numbers) which reflect changes in building style and materials and to match current census data (52,53).

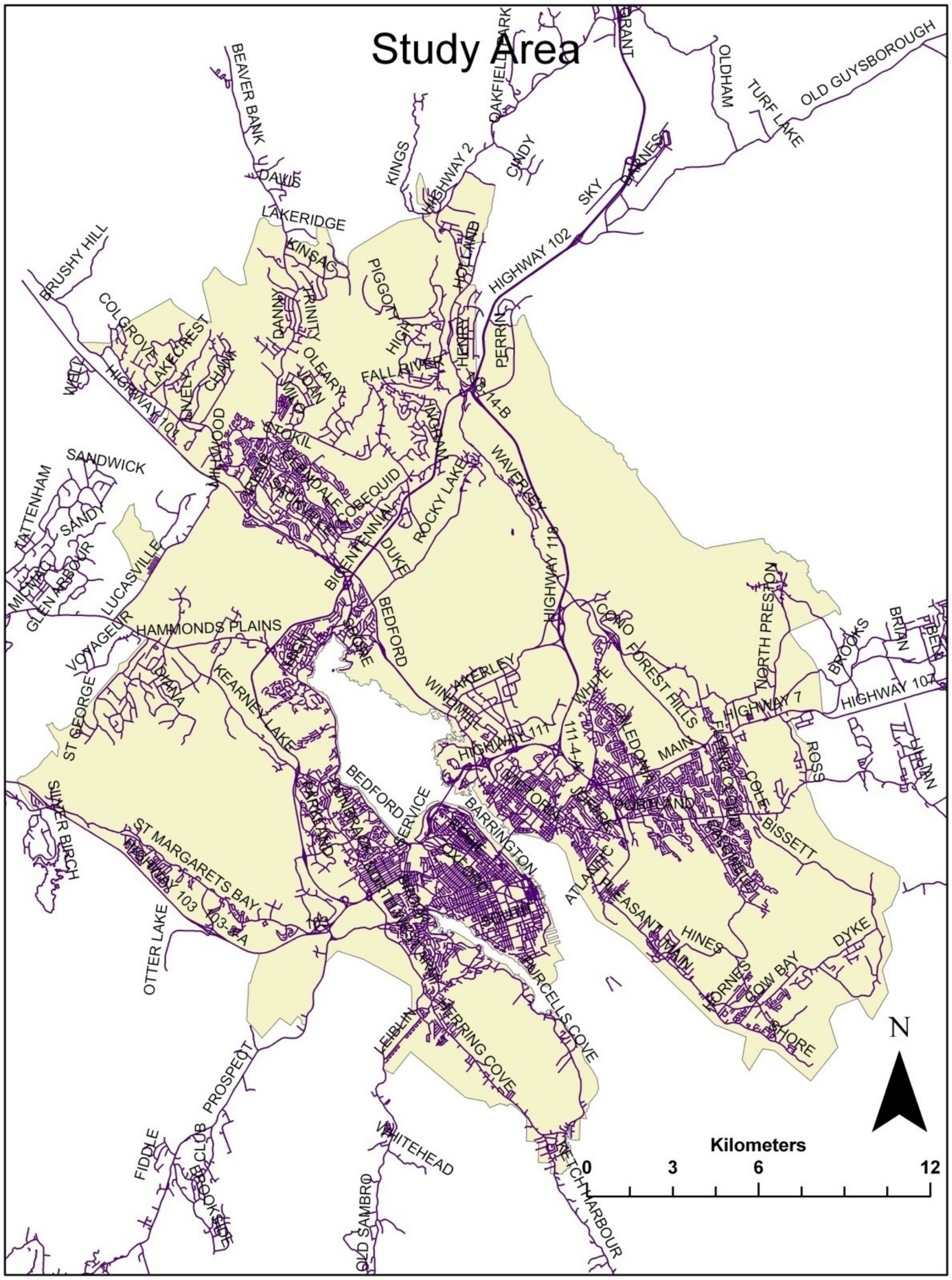


Figure 1. The region used in the 2009 HIAQS, the boundary includes the major urban centres and feeder suburbs of Halifax.

The inclusion criteria are as follows; participants had to be home owners of residences located within the urban or sub-urban region of Halifax, living in a detached home and contain non smokers only. Each age category had 10 houses for both the winter and summer sampling seasons. 42 out of the 50 homes sampled in the first phase of the study were also sampled in the second phase of the study in the summer, eight new participants were recruited to replace the study dropouts. The sample size was identified through power calculation to yield a power of 0.90 with an alpha of 0.05 using either five or seven day sampling – seven day sampling was used to better capture any changing behaviour on the weekends.

During the two sampling campaigns, both indoor and outdoor data was collected on various components of air pollution (Table. 1) using both passive and active sampling methods. Home ventilation rates and both baseline and daily activity questionnaires to establish an understanding of the household behaviour. The sampling took place over nine week period in both the summer and winter, with approximately six homes being sampled each week over a seven-day period. Each sample required eight visits to the participating home, with all air pollution components being sampled for the full seven days and a follow up visit to vacuum dust. Some components were sampled in continuous 24-hour periods (analysis provided a summary value for the period) while others were sampled continuously in real-time using one minute averages for the full week. Study sampling equipment was also co-located with the NAPS site for assessment of instrument error and calibration.

The sampling method and study design resulted in 350 outdoor 24-hour samples for AQHI air quality parameters from fifty randomly selected and spatially distributed locations for both the winter and summer of 2009 with Federal Reference comparison data allowing for calibration.

The project, and ancillary data analysis, was given ethical approval by both Health Canada and Dalhousie University and reviewed each year. The current work has also been ethically reviewed by the Dalhousie University Office of Research Ethics Administration (human research ethics - Project # 2011-2420).

Additional data was garnered from Environment Canada including all reported AQHI values for 2009 as well as wind speed and direction, temperature and dew point and relative humidity from the Halifax Dockyards Meteorological site, daily precipitation data was gathered from the Halifax Regional Municipality (HRM) Pockwock Water Reservoir meteorological site. While NAPS data was provided by the Nova Scotia Department of Environment.

This unique data set provides an opportunity to study the spatial and spatial-temporal variation of various components of urban air quality and to use this data to expand our understanding of how the AQHI represents air quality at the sub-urban scale.

Table 1. Measurements, and instrumentation used for AQHI pollutants in the 2009 HIAQS study. The location of sampling and the time frame of data recording have also been identified.

Component	Sample method	Analysis method	Sample period
NO_2, O_3	Ogawa passive samplers	Ion chromatography	24-hour
Particulate matter $PM_{2.5}$ (real time)	TSI DustTrak nephelometer	Numerical data	One minute averages
Particulate matter $PM_{2.5}$ (mass and capture)	Filter-based system using Harvard Impactors	Micro-balance scale, chemical analysis, x-ray diffraction	24-hour
Coordinates	Mobile GPS	Numerical data	NA

2.2 Field Equipment and Methods

Both NO_2 and O_3 were sampled using Ogawa Passive Samplers (Ogawa & Co., Pompano Beach, FL, USA) for both the summer and winter, though in the winter double sided Ogawa Samplers were used, while in the summer both pollutants were assessed using the same filter. 10% of the samples were placed in the field with duplicate samples and 10% were matched with blanks to assess potential laboratory and transport contamination. The Ogawa sampler uses a carbonate-coated quartz-fibre filter coated in tri-ethanolamine (TEA) to collect NO_2, while O_3 is collected via a sodium nitrite-coated quartz-fibre filter (54,55). Both the NO_2 and O_3 coated quartz-filters were purchased from the manufacturer and samples were analyzed by Environment Canada according to the Ogawa Standard Operating Procedures (SOP). Detailed description of the analysis method for both NO_2 and O_3 is available in Wheeler et al 2011(52,53).

$PM_{2.5}$ mass concentration was assessed using two different methods – integrated 24-hour samples and near real-time as one minute averages. The integrated samples were conducted using Harvard Impactors (HCI, Harvard School of Public Health, Boston, MA, USA) powered by portable pumps either SKC Leyland Legacy (SKC Inc., 863 Valley View Road, Eighty Four, PA 15330, U.S.A) or a BGI pump (BGI Inc., Waltham MA, USA) operated at a flow rate of 10 l min^{-1}. The Harvard Impactor contained a $PM_{2.5}$ selective impactor plate coated with silicone grease to remove particles larger than 2.5 μm from the sample. The collection media were pre-conditioned (for 24-hr in a room at 20°C and 40 ± 2% RH, (56)) and pre- weighed 37 mm diameter, 2μm pore size, Teflon filters (Pall Inc, Port Washington, NY, USA). Like the NO_2 and O_3 samplers 10% of the samples were assigned duplicates and blanks. Samples were processed and analyzed buy the Alberta Research Council Laboratory (Vegreville, AB).

$PM_{2.5}$ mass concentration was also measured in near real time at each sample site using TSI DustTrak Model 8520 laser nephelometers photometers (TSI Incorporated, Shoreview, MN, USA). DustTraks were operated at a flow rate of 1.7 l min^{-1} with a time interval of one minute. Two DustTraks were installed at the NAPS station; one with a Nafion dryer attached to reduce relative humidity and all DustTraks were housed in waterproof temperature controlled enclosures.

2.3 CURRENT STUDY

The data were received from the ancestral study in the form of excel spread sheets identifying individual sites and values for one chemical for each sampling campaign per file. Spatial coordinates were received in a separate file. These data were refined to present a pair of separate data tables, one for each season identifying the sample site number, dates of sampling, NO_2 and O_3 concentration expressed as a volume mixing ratio (ppb) and $PM_{2.5}$ expressed in mass per volume concentration (µg m^{-3}).

Various steps were taken to refine the raw data to a useful state. The sample site at the NAPS site was running two $PM_{2.5}$ mass concentration samplers (identical to the samplers located at the sample sites) to provide a stronger sample for calibration with the Federal Reference Method (FRM) sampler located on site (Partisol 2025). These values were average to provide one sample value per day at the NAPS site- if there was a sampling error in one of the samplers, the other value was used (this occurred twice in the winter sampling campaign, once in the summer sampling campaign). The available data were then compared to data collected from the NAPS site to test the accuracy of the samplers when compared to the NAPS site. Unfortunately no data were available from the NAPS site for the sample period for NO_2 or $PM_{2.5}$ so only O_3 was compared.

At the sample sites a differing method was used to correct for failures in either the Harvard Impactors or the pumps powering them. As previously noted DustTrak monitors were co-located with the Harvard Impactors and measuring $PM_{2.5}$ in near real-time. The DustTrak readings for the complete study were corrected using a correction factor developed during the study and then were uses to create a Reduced Major Axis (RMA) model of the relationship between the Harvard Impactors and the DustTraks (20,52). This model was then used to replace lost samples during the study at the sample sites.

2.4 AQHI CALCULATION

Once the data had been prepared a daily site AQHI was calculated using Eq (1)(32)

$$PM_{2.5}AQHI=\frac{10}{10.4}\times(100\times\left(e^{(0.00871\times NO_2)}-1+e^{(0.000537\times O_3)}-1+e^{(0.000487\times PM_{2.5})}-1\right) \quad (1)$$

Where NO_2 is the daily concentration of NO_2 in part per billion (ppb), O_3 is the daily concentration of O_3(ppb) and $PM_{2.5}$ is the daily concentration of $PM_{2.5}$ in µg m^{-3}.

This is a simplified version of the actual AQHI calculation which uses a three hour rolling average of the three pollutants – which was not available for this study – in place of the daily concentration. This provided a daily AQHI value for all sample days at all sample sites, and the NAPS site where there were all three pollutants for a given sample day. These values were then merged with the daily reported AQHI values into two seasonal campaign master tables which were used as the base point for all further analysis.

2.5 STATISTICAL ANALYSIS

Statistical analyses were conducted using both Sigmaplot (v 11.0) and SAS (v 9.2) to evaluate seasonal comparisons, to complete within season analysis and to generate the reported AQHI analyses. These analyses were limited by small sample sizes in many situations, reducing the accuracy and power of various computations particularly for the within-season analysis. To minimize the likelihood of introducing errors, both a Shapiro-Wilk normality test (57,58) and a Levene Median equal variance test (59,60) were conducted to insure the data distributions were normally distributed and homoscedastic before any test was conducted in SigmaPlot. Visual representation of the data was prepared using three programs SigmaPlot, Exel (v 2007) and IGOR Pro (v 6.2.2.2). Standard colour sets were used to represent the seasonal values and site measurements to improve clarity. Data were then migrated into ArcGIS 9.3 where mapping and spatial analysis was conducted.

2.5.1 NAPS SITE ANALYSIS

An attempt to compare between the co-located samplers at the NAPS site was undertaken, however only O_3 data was available for the two sampling campaigns, NO_2 and $PM_{2.5}$ were not available. Weekly O_3 Ogawa samplers from the NAPS site were compared to the NAPS near real time auto-analyzer data by producing a summary value for the weekly sample period from the NAPS data. This data was then regressed to produce a R^2 value between the two forms of sampling (20).

2.5.2 BETWEEN SEASON ANALYSIS

Various parameters were compared between the seasons including meteorological variables, pollutants and AQHI values. Using statistical comparison to define the differences between the seasons weather patterns as well the pollutant levels allows for understanding the underpinning differences in the seasons and how these differences affect the seasonal AQHI values. All data for the between season analysis are presented in graphical form using two programs, SigmaPlot and IGOR Pro. The data are presented in boxplot form for bin comparisons of data and in line graph form for temporal analysis. IGOR Pro was used to produce wind rose plots to give a visual representation of wind direction and speed.

To compare between the seasons only, the 42 sites which were used in both seasons were included to reduce spatially controlled error. All data pairs were pre tested for normality and equal variance to insure the appropriate test for the data distribution were used. All variable pairs were tested using the Mann-Whitney Rank Sum Test as the pre tests all showed that the data was not normally distributed or did not have equal variance – is normal for environmental data. The Mann-Whitney Rank Sum Test is one of the most common of the non-parametric tests for assessing two groups of samples and is commonly used in environmental research (60,61). A secondary test of the sample reported weekly Mean AQHI values was tested using a paired T test as the data was normally distributed using the weekly means rather than daily values. Statistical tests in this section had good power as large sample sizes were used.

2.5.3 Within season analysis

Throughout the within season analysis both sampling campaigns were treated identically and will be covered simultaneously. Statistical analysis was conducted using SigmaPlot and visual data presentation was conducted using SigmaPlot, Excel and IGOR Pro. Each week of the sampling campaigns were tested individually using a one-way ANOVA test prefaced with both normality and equal variance tests. If these tests were passed then the standard ANOVA was conducted at a significant of $p<0.050$, If one or both was failed then a Kruskal-Wallis one-way ANOVA on Ranks was conducted also at a significance of $p<0.050$. If the ANOVA was failed and there was no difference between the groups then the testing run was terminated.

If the ANOVA was passed, meaning that one or more groups was significantly different from one or more of the other groups then multiple pair wise comparison tests were conducted to identify the differences at a significance of $P<0.050$. Three test were used: Holm-Sidak Test, Tukey Test and Dunn's Test which is the only test available on Sigma Plot for treatment groups of different sizes. All three of these multiple comparison tests have been used previously in air pollution research (62-66). Regardless of the results of the two preceding test either a Pearson Product Moment Correlation or Spearman Rank Order Correlation (described by Zar 1972) (67,68) was conducted to explore the linear correlation of the data during the week to gain a better understanding of the temporal autocorrelation between the sites. This form of correlation has been previously used in various air pollution studies in a similar manner to explore linear associations between changing variables (69-71). The choice of test was driven by the underlying data distribution of the week, either parametric or non-parametric. A secondary analysis was conducted on weeks were data was missing from either sample sites or the NAPS station by removing that site and re-running the ANOVA and multiple comparisons to improve the power of the test.

The data for each week was presented using several visualizations included line graphs of the daily site, NAPS and reported AQHI values, line graphs of the daily deviation away from the reported AQHI for each sample site, box plot of the data and a wind rose of the weekly wind speed and direction.

2.5.4 Reported AQHI analysis

In an attempt to better understand the variation in data with respect to how the AQHI is reported to the public a re-analysis of the data was conducted. The AQHI is reported to the public on a 1 to 10+ scale however the value is calculated as a decimal place value and rounded for greater clarity. To reflect this all AQHI values were rounded to the nearest whole number, including zero to better reflect ground level air pollution levels. Using SAS, cross tabulations were conducted to identify inaccuracy of the AQHI as it would be reported to the public. These tabulations were conducted in three phases: all data, stratified by site and stratified by date. The data is presented using line graphs produced by SigmaPlot showing the reported AQHI and the percent of AQHI values from the sample sites that were a different value than the reported AQHI and mapped using ArcGIS (method described below).

2.5.5 MAPPING AND SPATIAL ANALYSIS

During the execution of this study various maps were constructed using ArcGIS. These maps can be classified into two types – presentation maps and analysis maps. To create the base map for the study various layer were combined to create a single base then over laid with either data to be presented or the results of spatial analysis. The base map was generated by over laying road data onto a digital elevation map (DEM). Spatial analysis was conducted by using interpolation methods found in the Spatial Analysis extension of ArcGIS. Interpolation was conducted seasonally on all three pollutants and the AQHI values and is presented as a method of visualizing the data to better understand the variation of the pollutants and AQHI metric over the sample area. Several different interpolation methods were conducted including: Kriging, inverse distance weighting, spline and point interpolation however the natural neighbours interpolation method presented the best visualization of the data. Full description of the natural neighbours interpolation method can be found in Chapter Two of Interpreting Multivariate Data, by Barnett, 1981 (72).

Secondary mapping was also undertaken using the cross tabulated data. In this analysis the number of times each sample site was different from the reported AQHI was converted to a percent and plotted as one of four shapes based on 25% increments of non-agreement while the sample week was recorded using various colours. Each sample site is the colour of its sample week – the same as all other points sampled during that particular week and a shape depending on the percent of non-agreement with the reported AQHI. Non-agreement was tested on a daily basis.

CHAPTER 3.0 RESULTS

The results from this study are presented in the following chapter and include NAPS site comparison, seasonal meteorological features such as precipitation, temperature, wind speed and wind direction. The meteorological results are presented in the form of bar charts and wind roses. This will be followed by seasonal comparison of AQHI values between reported, sampled and NAPS station sampling locations. The three air pollutants ($PM_{2.5}$, NO_2 and O_3) that are used to calculate the AQHI will also be compared, however these values were not available for the Environment Canada reported AQHI. These data will be presented via descriptive statistics as well as bar and time-series plots.

The following sections (3.3, 3.4) report the weekly variation in AQHI values through time series plots, bar charts and weekly wind roses. Statistical assessment of the similarity and correlation of the weekly AQHI values from the sample sites, NAPS station and reported AQHI values are also reported. Section 3.5 uses the 42 sample sites that were repeated during both sampling campaigns. The results for these sites are reported as a series of statistical significance tests and as bar chart format.

The final section of the results is the spatial interpolation which was undertaken for each season. This data is reported as spatial maps of the study region using natural neighbours interpolation. It is important to note that this is a space filling interpolation method not a predictive model and while it does provide a interpolated couture surface this is not a predictive layer. The results should therefore be used to improve our understanding of how the AQHI and component pollutants vary over the sample region not as a model of values.

3.1 NAPS SITE SAMPLER INTER COMPARISON

Comparisons between the NAPS site Environment Canada monitoring data and the HIAQS co-located samplers were only conducted only O_3 because the data for NO_2 and $PM_{2.5}$ were not available. The NAPS site records data in near real time and summary values were taken for each Ogawa sampler sample period to perform the comparison. Agreement was strong (R^2=0.69) during the winter (Figure. 2) with higher O_3 values however weak during the summer (R^2=0.00)(Figure.3).

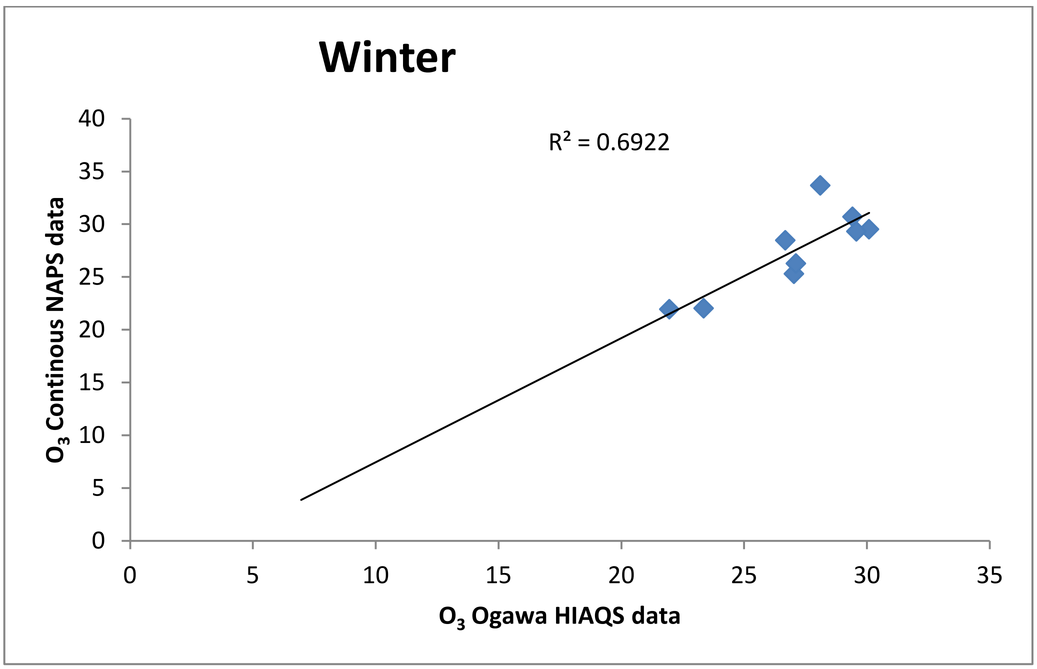


Figure 2. Regression plot between NAPS O_3 values and weekly O_3 Ogawa samplers for the winter sampling campaign.

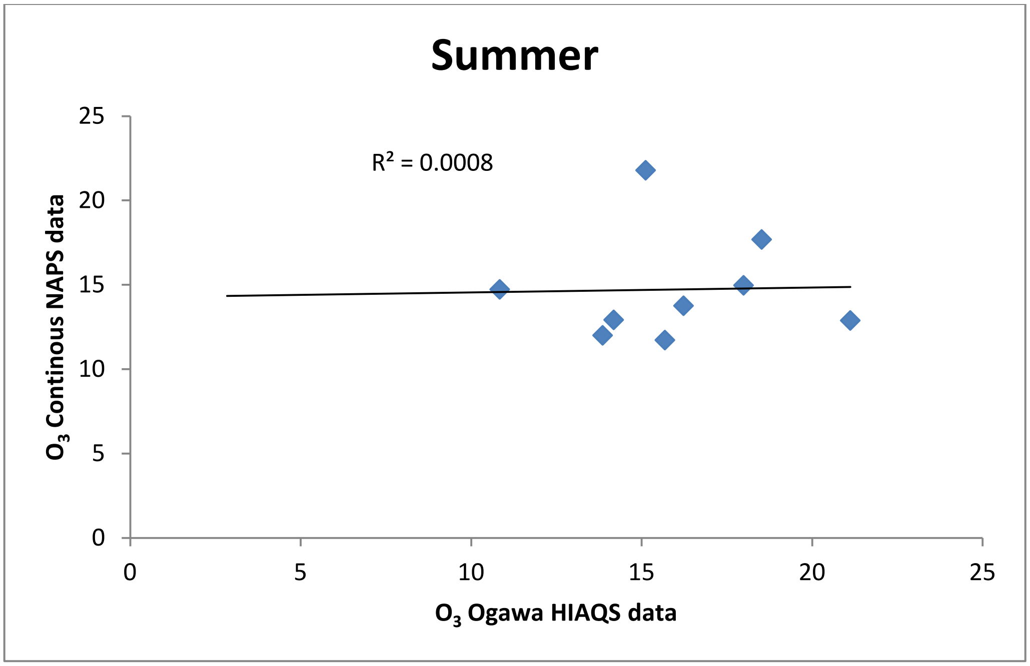


Figure 3. Regression plot between NAPS O_3 values and weekly O_3 Ogawa samplers for the summer sampling campaign.

3.2 SEASONAL WEATHER

Halifax is located in a region of high climatic variability, Nova Scotia is located in the mid-temperate zone with a modified continental climate zone with local conditions controlled by elevation and proximity to the coast. The Halifax region is predominantly in the Atlantic Coastal zone with warm winter temperatures and cool summers however in the west, further from the ocean it is influenced by the Eastern Nova Scotia zone which has both colder and drier winters and a warmer summer there is also less rain fall and fog (73).

Seasonal weather is reflective of the local climate with temperatures, predictably, lower in the winter along with dew point and relative humidity, although there were more peak precipitation days in the winter (Table. 2 and Figure. 4). Winter wind speeds are higher than summer winds however there are higher short-term events, e.g. tropical storms, during the summer sampling campaign (Table. 2 and Figure. 4). Wind direction shows more variation, with summer winds being dominated by a strong south eastern component and a small south western component. During the winter sampling campaign however a strong western component varies from south west to north west with a secondary south east component (Figures. 6 and 7). All variables were tested using the Mann-Whitney Rank Sum test and all variables indicated a statistically significant difference ($p=<0.001$) except for precipitation and relative humidity.

Table 2. Weather metrics for both winter and summer sampling campaigns.

	Sample Metrics	Maximum	Minimum	Median	Range
Winter season	Temperature	6.63	-9.49	-0.79	16.11
	Relative humidity	95.74	39.32	74.74	56.41
	Dewpoint	5.38	-18.39	-4.99	23.77
	Precipitation	57.20	0.0	0.40	57.20
	Wind speed	13.89	0.00	2.78	13.89
Summer season	Temperature	25.44	12.90	17.60	12.54
	Relative humidity	94.66	57.06	81.82	37.60
	Dewpoint	19.58	5.28	14.49	14.30
	Precipitation	26.70	0.00	0.30	26.70
	Wind speed	15.00	0.00	1.94	15.00

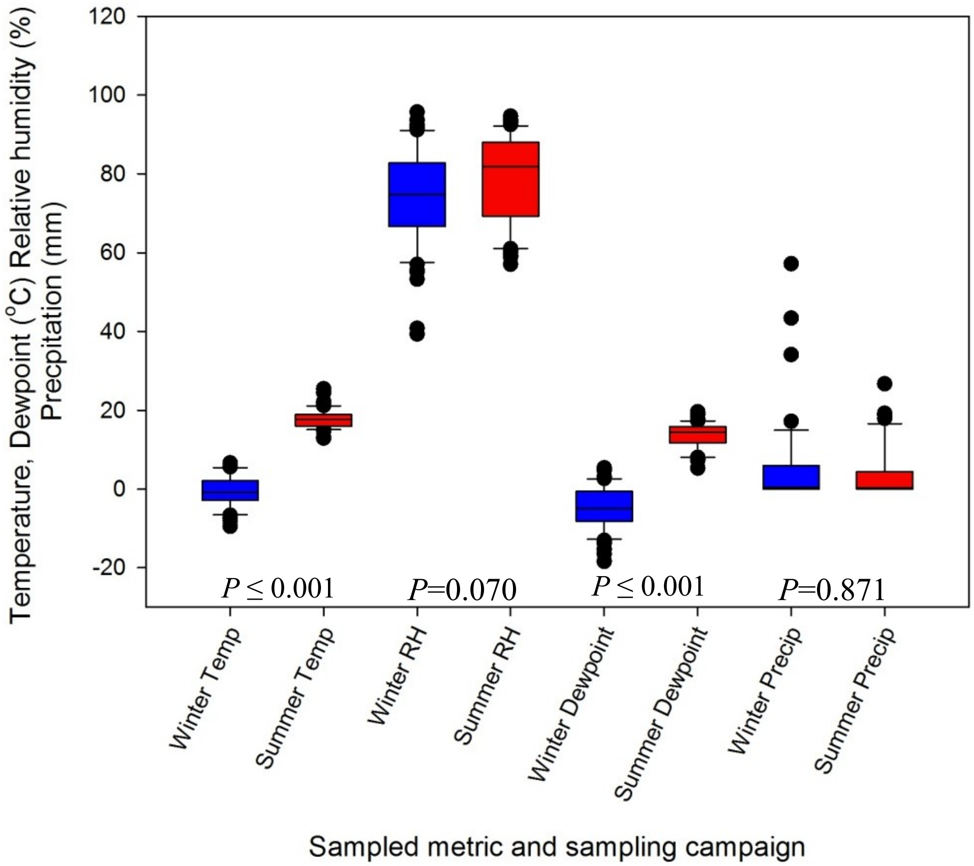


Figure 4. Weather metrics for both sampling campaigns, termperature and dew point

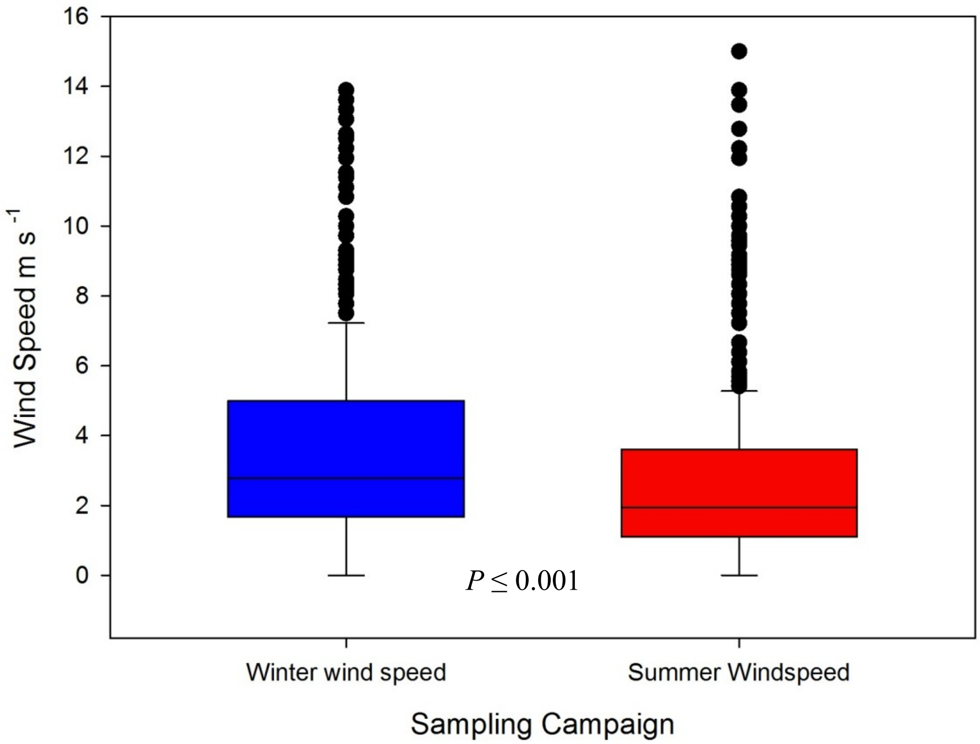


Figure 5. Wind speeds for both sampling campaigns, HIAQS, 2009.

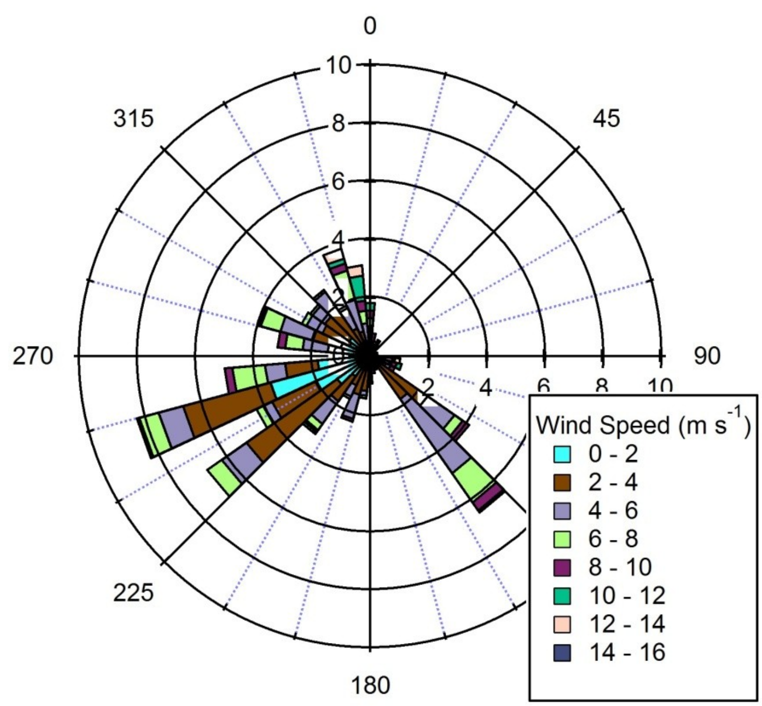


Figure 6. Wind direction and speeds for the winter sampling campaign, HIAQS 2009.

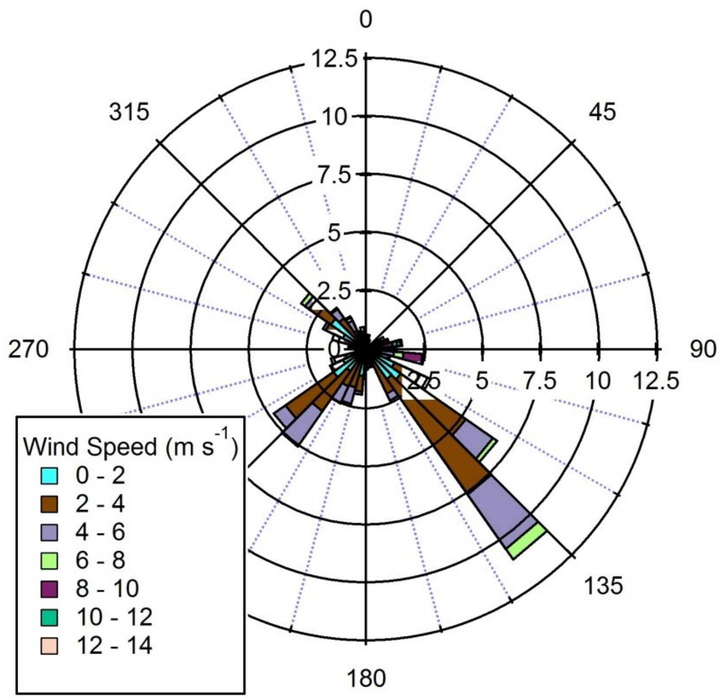


Figure 7. Wind speed and direction for the summer sampling campaign, HIAQS, 2009.

3.3 SEASONAL COMPARISON

The data variation for both sampling campaigns is encapsulated in Table. 3. Overall variation in the winter AQHI values are shown as a time series in Figure. 8, there is little evidence of a seasonal trend however some intra-season variation is demonstrated. A similar pattern is established in the summer season with variation occurring between sampling days but no overall seasonal trend (Figure. 9). Reported AQHI values were found to be significantly different from the sample sites but the same as the downtown NAPS station for both seasons using Kruskal-Walls ANOVA on Ranks and Dunn's method for multiple comparisons at a significant level of p=0.05 (winter Figure. 10, summer Figure. 11).

Table 3. Summation of descriptive statistics from the AQHI data set from both sampling campaigns, this demonstrates the non-parametric nature of the overall data set.

	Sample Sites	Sample Size	Maximum	Minimum	Median	Range	Standard Deviation	Skewness	Kurtosis
Winter season	Sample sites	317	3.62	1.29	2.06	2.33	0.38	0.76	0.90
	NAPS site	60	4.42	1.70	2.61	2.72	0.53	0.94	1.64
	Reported AQHI	61	4.04	1.73	2.59	2.31	0.45	0.52	0.61
Summer season	Sample sites	337	2.71	0.49	1.12	2.29	0.34	0.92	1.57
	NAPS site	61	3.09	0.83	1.66	2.25	0.52	0.82	0.07
	Reported AQHI	60	2.43	0.30	1.61	2.43	0.43	-0.39	0.29

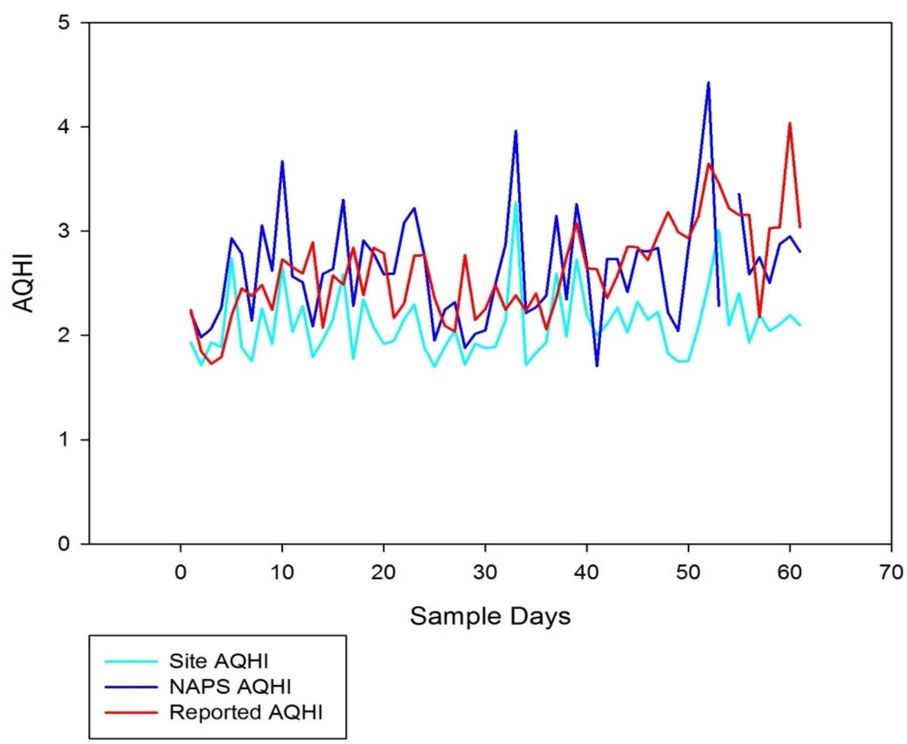


Figure 8. Time series plot of the variation in AQHI values from the winter sampling campaign

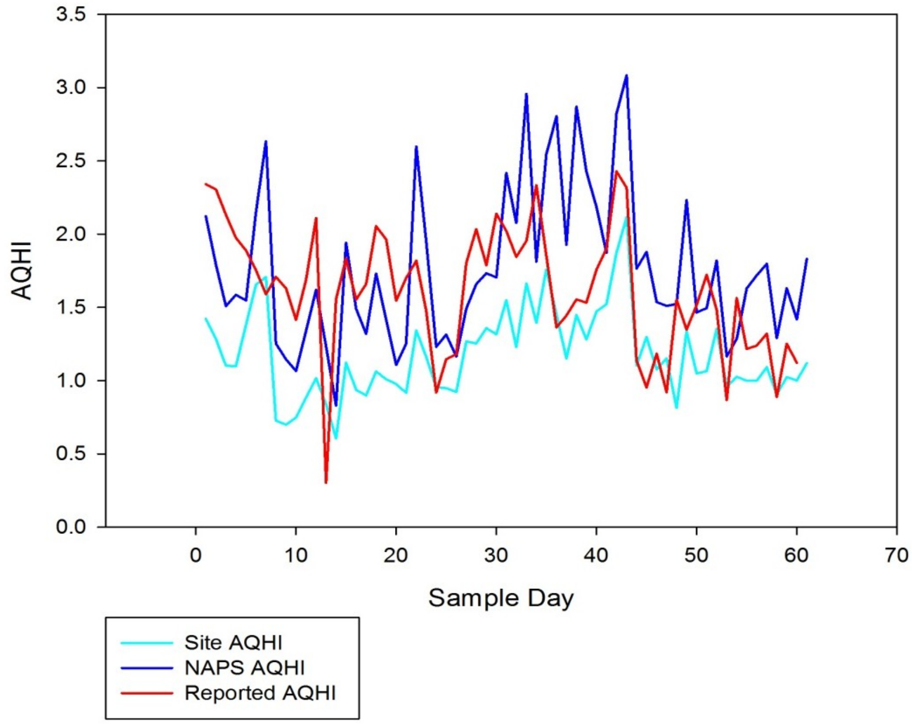


Figure 9. Time series plot of the variation in AQHI values from the summer sampling campaign

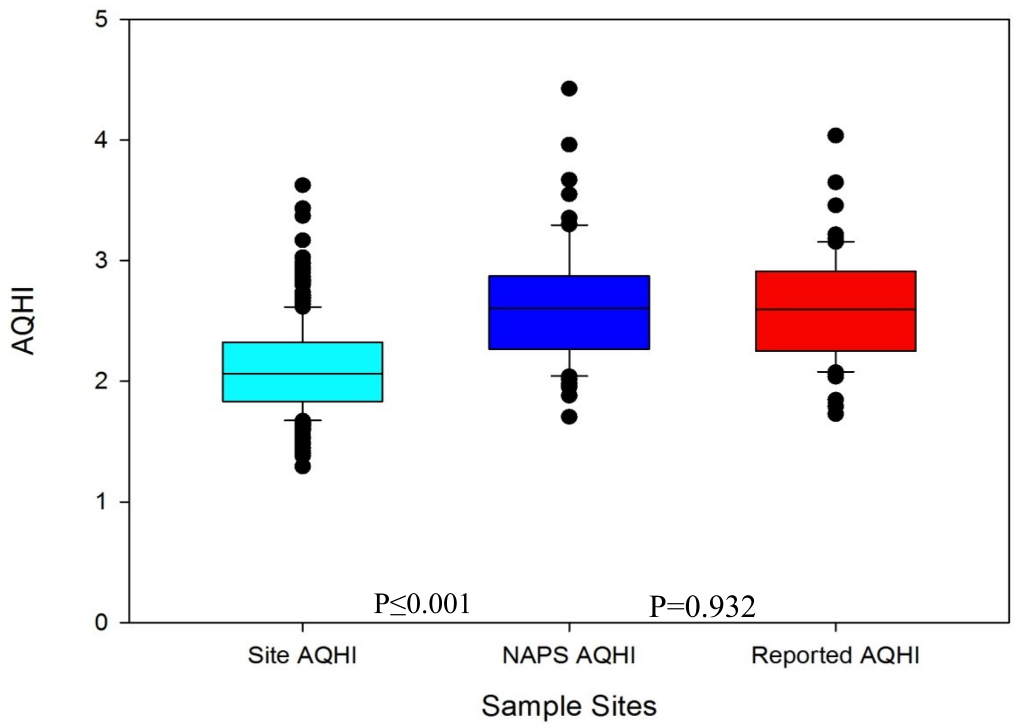


Figure 10. AQHI values for the winter sampling campaign

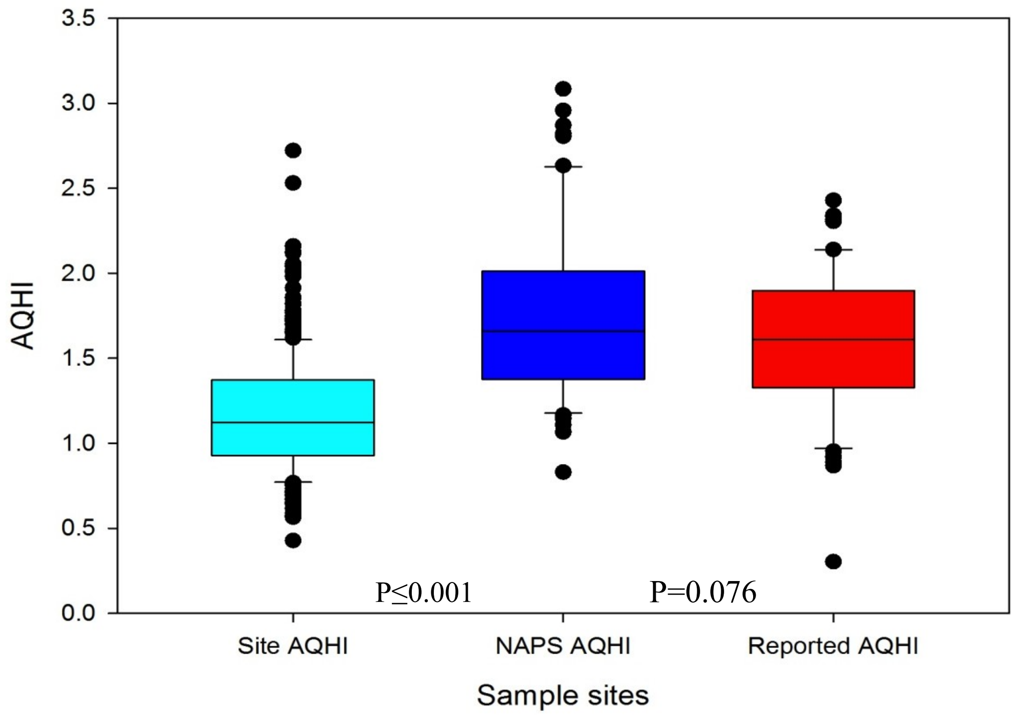


Figure 11. AQHI values for the summer sampling campaign

The AQHI component pollutants vary between the sample sites and the NAPS site for both sample campaigns except for O_3 in the winter campaign. Comparisons were undertaken using the Mann-Whitney Rank Sum Test (Figures. 12 and 13). While all pollutants are higher in the winter phase, O_3 is of particular note (Table. 4). Values could not be compared to the component pollutants for the reported AQHI as the value was provide from Environment Canada already calculated.

Table 4. Descriptive statistics for AQHI component pollutants

	Sample Site Pollutant	Sample Size	Maximum	Minimum	Median	Range	Standard Deviation	Skewness	Kurtosis
Winter season	Sample site NO_2	338	23.4	0.7	4.8	22.7	4.1	1.4	2.3
	NAPS site NO_2	60	26.3	1.1	10.5	25.2	4.9	0.7	0.7
	Sample site O3	338	33.7	19.1	27.1	14.6	3.3	-0.3	-0.5
	NAPS site O3	60	30.1	21.9	27.1	8.1	2.6	-0.8	-0.5
	Sample site $PM_{2.5}$	333	19.7	0.1	4.5	19.7	3.3	1.1	1.7
	NAPS site $PM_{2.5}$	57	14.0	0.7	5.7	13.3	3.1	0.4	-0.3
Summer season	Sample site NO_2	331	13.8	0.6	1.8	13.1	2.3	1.5	2.3
	NAPS site $NO_{2.}$	61	18.3	0.7	5.5	17.7	0.6	0.8	0.2
	Sample siteO3	331	22.6	5.0	13.6	17.5	0.2	0.2	0.1
	NAPS site O3	61	21.1	10.8	15.7	10.3	0.4	0.1	-0.4
	Sample site $PM_{2.5}$	331	17.8	0.1	4.9	17.7	0.2	1.2	1.1
	NAPS site $PM_{2.5}$	61	24.4	1.9	6.8	22.5	0.6	1.5	2.9

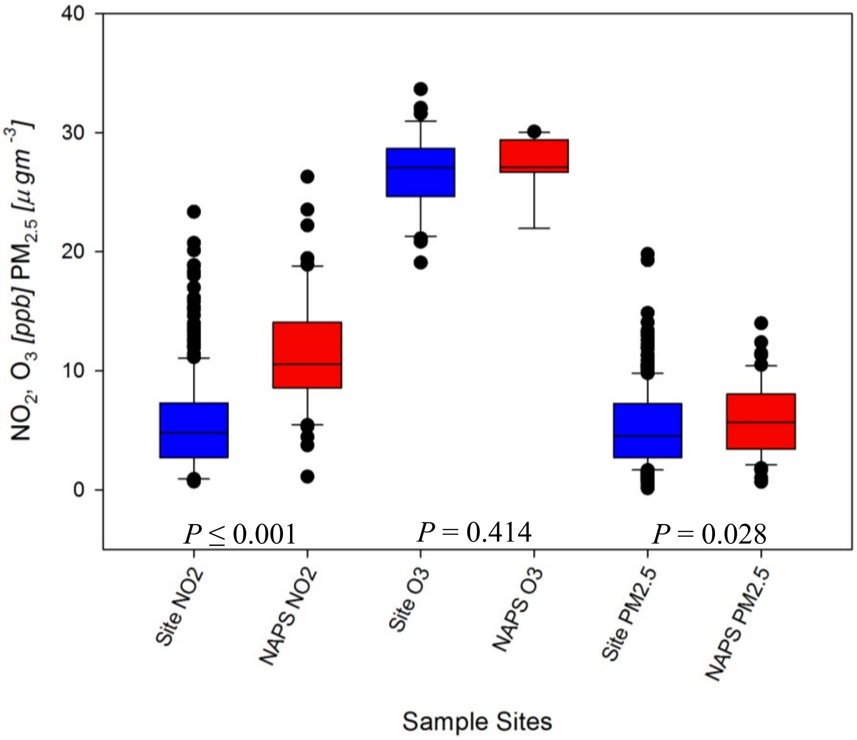


Figure 12. The AQHI component pollutants compared between the sample sites and NAPS station during the winter sampling campaign

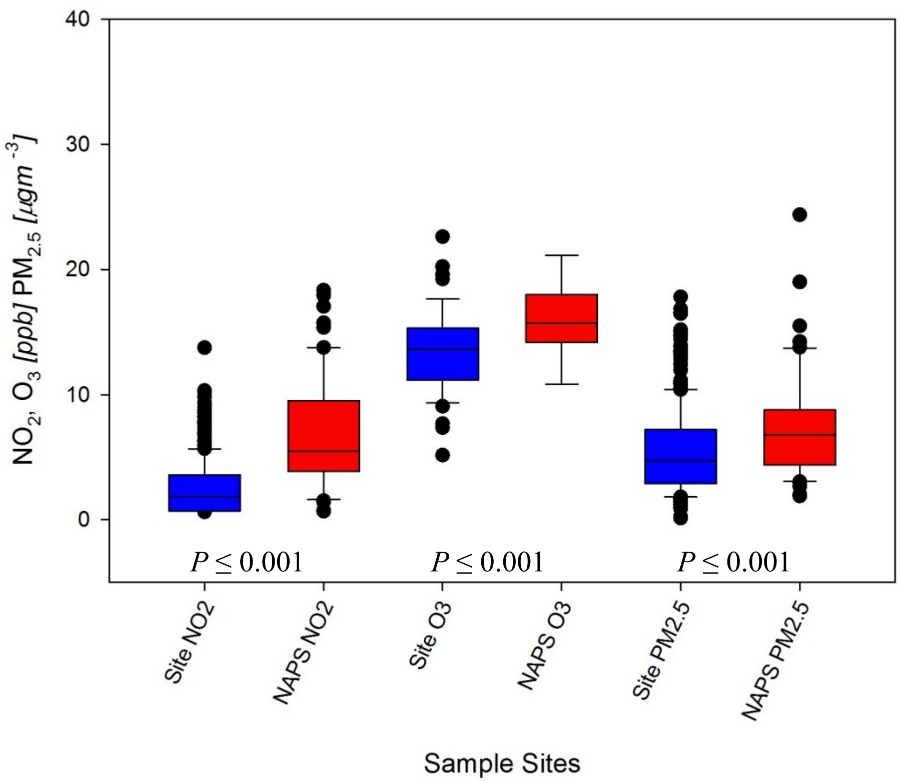


Figure 13. The AQHI component pollutants compared between the sample sites and NAPS station during the summer sampling campaign.

The component pollutants also vary temporally over the sampling campaigns. Figure. 14 shows this variation for each of the three component AQHI pollutants over the sampling days for both the sampling campaigns in three panels. These panels show the three pollutants for both the site means and NAPS station values, pollutants components from the reported AQHI were not available.

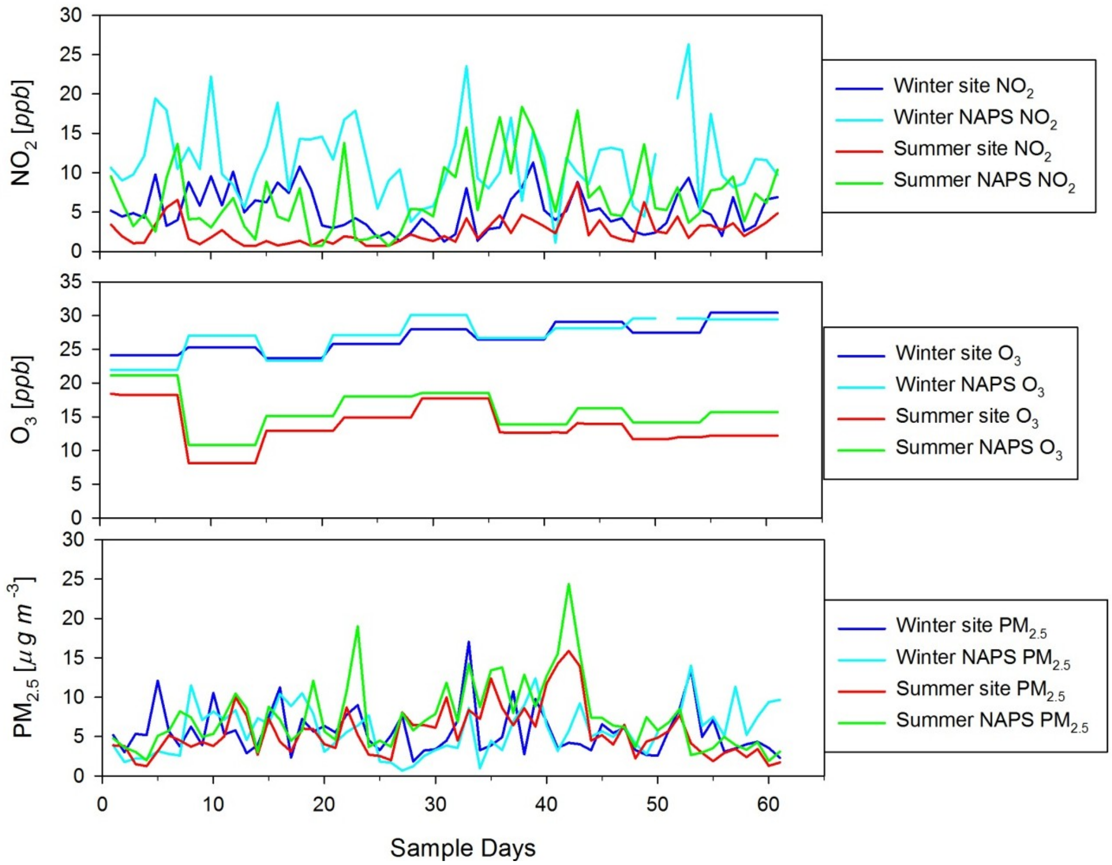


Figure 14. The three component pollutants of the AQHI values are shown in three panels, both summer and winter values are shows for each the NAPS site and the mean of the sample sites

3.4 WINTER SAMPLING CAMPAIGN

Weekly changes in AQHI values for the sample sites, NAPS site and reported AQHI are shown in Figure. 15. During the winter sampling phase of the Halifax air quality study, daily AQHI values were found to vary significantly between the reported AQHI values and the sample sites for four out the nine sampling weeks. Seven individual sampling sites demonstrated significant differences between the site recorded values and the reported AQHI values. The locations of the sampling sites are identified by sample week in Figure 16. Table 5 provides a summary of all the correlations for the winter sampling campaign. These values are calculated by summing the number of sample sites which vary together for each sampling week.

For each sample week statistical analysis has been produced following the method previously described. In addition, weekly time series graphs of the daily AQHI, deviation of the AQHI from the reported AQHI, box plots of the data points and a wind rose of the weekly weather have been produced. Only the first week of the sampling campaign is shown here the remainder have been placed in Appendix. A. Meteorological data was obtained from the Halifax Naval Dockyards (Halifax Harbour narrows) weather station through the use of publically available Environment Canada data.

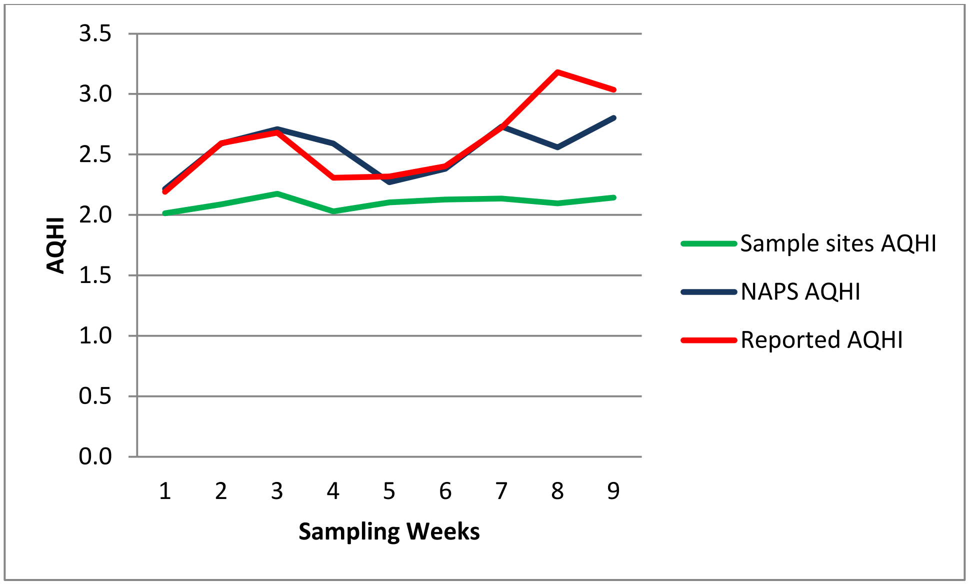


Figure 15. Median AQHI values for the nine sample weeks of the winter sampling campaign compared with the NAPS site and reported AQHI.

Table 5. This table is a summation of the correlations between the sample points for the winter sampling campaign.

Sample week	Correlation between sites	Correlation between sites and NAPS site	Correlation between sites and reported	Correlation between NAPS and reported	Total
1	2	2	1	0	5
2	12	0	0	0	12
3	3	3	3	0	9
4	2	2	0	0	4
5	5	2	0	0	7
6	6	3	1	0	10
7	1	0	1	0	2
8	11	0	5	0	16
9	6	1	0	0	7
Total	48	13	11	0	72

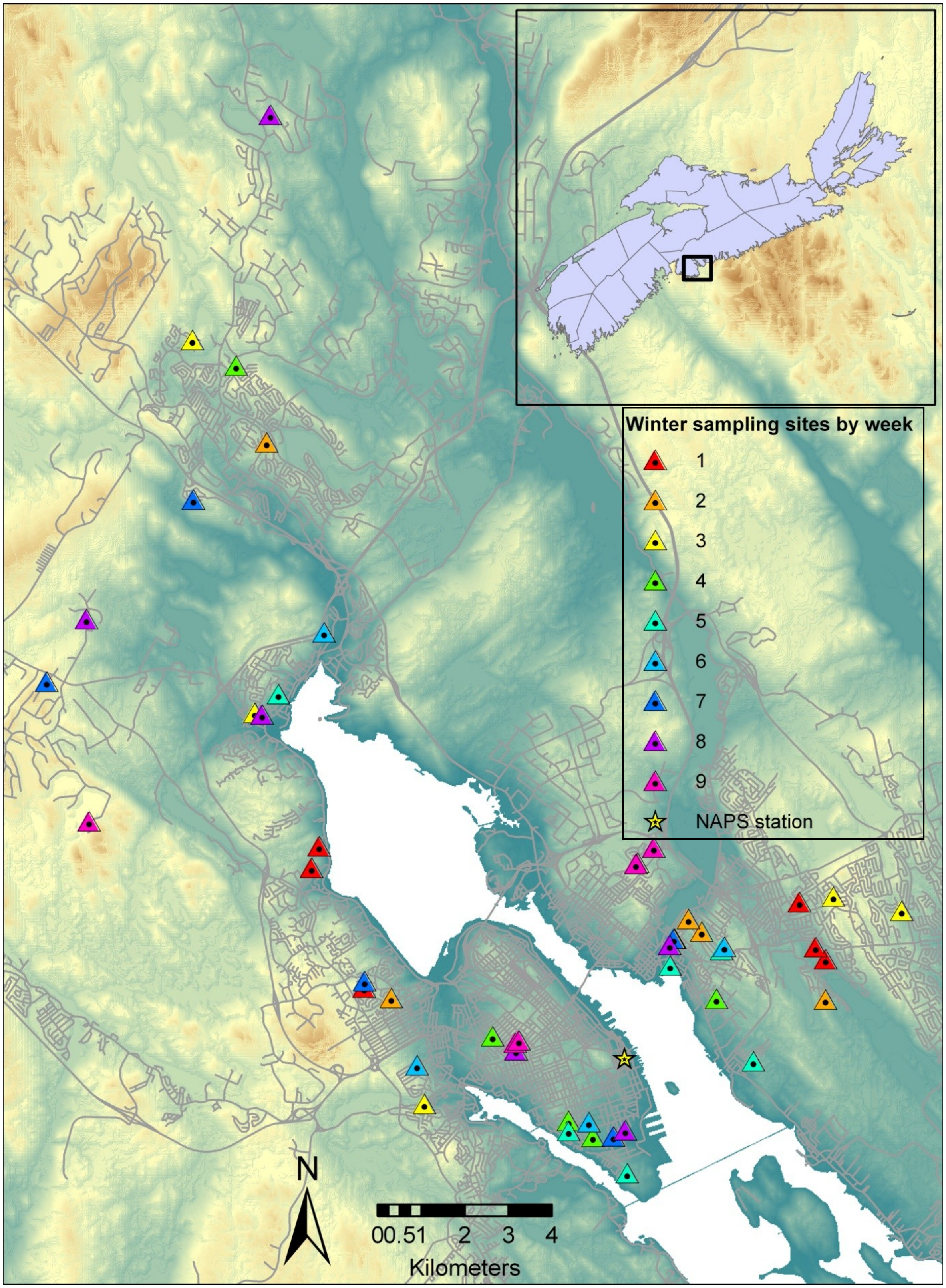


Figure 16. Sample sites identified by week (1-9) for the winter sampling campaign.

3.4.1 Week one, winter sampling campaign (January 8 to January 14, 2009)

The maximum, minimum and median AQHI values for the week were 3.88, 1.27 and 1.95 respectively. The reported AQHI generally follows the city values however on January 12th there is an unusual peak for three city sample sites which is not reflected by the reported AQHI (Figure. 17). This can be seen in the normalized plot (Figure. 18) as a strong deviation from the reported AQHI value in all but two of the sampling sites. Box plots of the data by sample site are recorded in Figure. 19. Dominant wind patterns are from the South East (SE) with peaks of up to 10 m s^{-1} (Figure. 20).

Statistics were calculated using Kruskal-Wallis ANOVA and Tukey's Test for multiple comparisons and Spearman Rank Order Correlations for correlation coefficients. The Kruskal-Wallis ANOVA test is applied to non-normal data that has been ranked and tested in pairs. When a pair is tested and found not to be significantly different, all points with lower ranks are not tested as they will also not significantly different:

Normality Test (Shapiro-Wilk Failed (P < 0.050)
Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	**N**	**Missing**	**Median**	**25%**	**75%**
HFAX-001	7	0	2.018	1.918	2.180
HFAX-002	7	0	1.823	1.625	2.124
HFAX-003	7	0	1.760	1.554	1.918
HFAX-004	7	0	1.546	1.307	1.612
HFAX-005	7	0	2.275	2.113	2.353
HFAX-006	7	0	1.873	1.647	2.018
NAPS	7	0	2.214	2.065	2.783
reported	7	0	2.190	1.792	2.379

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	**Diff of Ranks**	**q**	**P<0.05**
HFAX-005 vs HFAX-004	231.000	5.353	Yes
HFAX-005 vs HFAX-003	186.000	4.310	Yes
HFAX-005 vs HFAX-002	128.000	2.966	No
HFAX-005 vs HFAX-006	126.000	2.920	Do Not Test
HFAX-005 vs reported	59.000	1.367	Do Not Test
HFAX-005 vs HFAX-001	57.000	1.321	Do Not Test
HFAX-005 vs NAPS	1.000	0.0232	Do Not Test
NAPS vs HFAX-004	230.000	5.330	Yes
NAPS vs HFAX-003	185.000	4.287	Yes
NAPS vs HFAX-002	127.000	2.943	Do Not Test
NAPS vs HFAX-006	125.000	2.897	Do Not Test
NAPS vs reported	58.000	1.344	Do Not Test
NAPS vs HFAX-001	56.000	1.298	Do Not Test
HFAX-001 vs HFAX-004	174.000	4.032	No
HFAX-001 vs HFAX-003	129.000	2.990	Do Not Test
HFAX-001 vs HFAX-002	71.000	1.645	Do Not Test
HFAX-001 vs HFAX-006	69.000	1.599	Do Not Test
HFAX-001 vs reported	2.000	0.0463	Do Not Test
reported vs HFAX-004	172.000	3.986	Do Not Test
reported vs HFAX-003	127.000	2.943	Do Not Test
reported vs HFAX-002	69.000	1.599	Do Not Test
reported vs HFAX-006	67.000	1.553	Do Not Test
HFAX-006 vs HFAX-004	105.000	2.433	Do Not Test
HFAX-006 vs HFAX-003	60.000	1.390	Do Not Test
HFAX-006 vs HFAX-002	2.000	0.0463	Do Not Test
HFAX-002 vs HFAX-004	103.000	2.387	Do Not Test
HFAX-002 vs HFAX-003	58.000	1.344	Do Not Test
HFAX-003 vs HFAX-004	45.000	1.043	Do Not Test

A result of "Do Not Test" occurs for a comparison when no significant difference is found between the two rank sums that enclose that comparison. For example, if you had four rank sums sorted in order, and found no significant difference between rank sums 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed rank sums is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the rank sums, even though one may appear to exist.

Spearman Rank Order Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-002	HFAX-003	HFAX-004	HFAX-005	HFAX-006	NAPS	reported
HFAX-001	0.393	-0.071	0.607	-0.071	0.429	0.750	0.214
	0.341	0.843	0.121	0.843	0.297	0.038	0.602
	7	7	7	7	7	7	7
HFAX-002		0.571	0.679	-0.607	0.964	0.536	-0.429
		0.150	0.074	0.121	0.000	0.181	0.297
		7	7	7	7	7	7
HFAX-003			0.321	-0.679	0.607	0.143	-0.500
			0.438	0.074	0.121	0.720	0.217
			7	7	7	7	7
HFAX-004				-0.071	0.643	0.821	0.286
				0.843	0.096	0.0145	0.491
				7	7	7	7
HFAX-005					-0.714	-0.107	0.821
					0.055	0.781	0.015
					7	7	7
HFAX-006						0.464	-0.536
						0.255	0.181
						7	7
NAPS							0.393
							0.341
							7

The pair(s) of variables with positive correlation coefficients and P values below 0.050 tend to increase together. For the pairs with negative correlation coefficients and P values below 0.050, one variable tends to decrease while the other increases. For pairs with P values greater than 0.050, there is no significant relationship between the two variables.

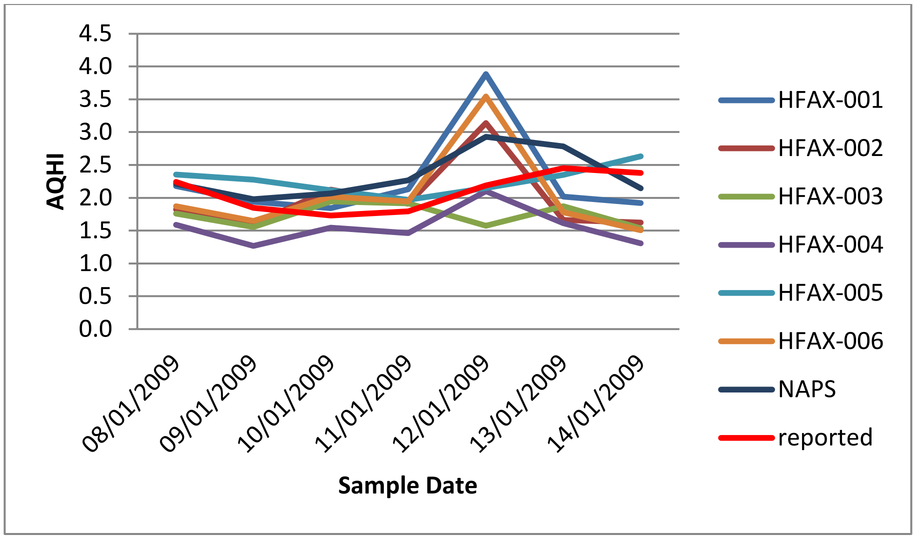


Figure 17. Time series of AQHI values for week one, winter sampling campaign.

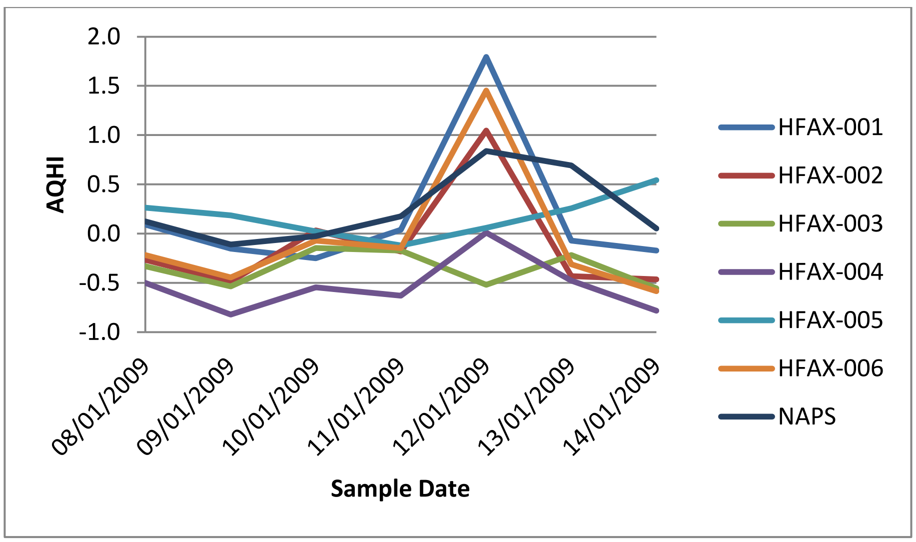


Figure 18. Time series of week one AQHI values normalized to the reported values.

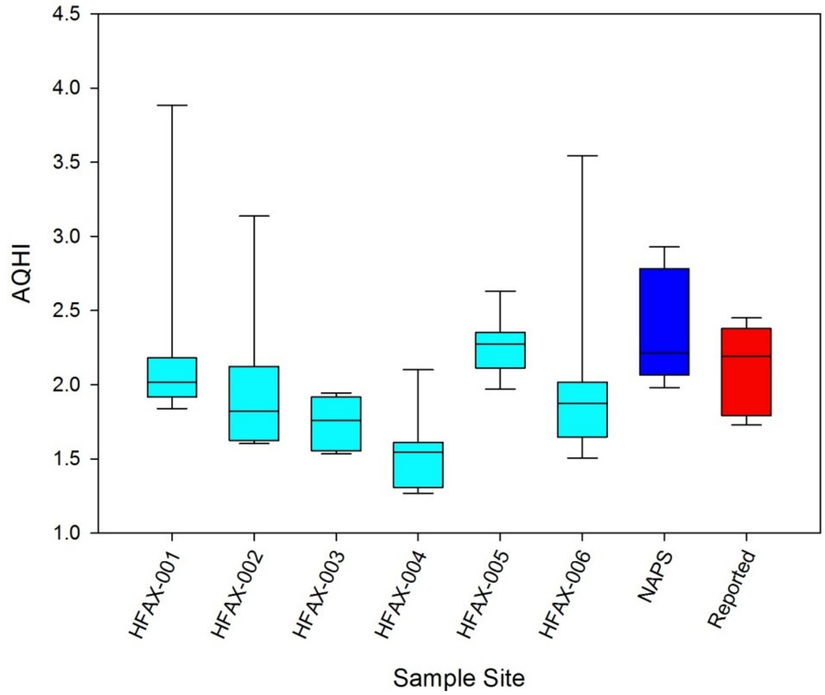


Figure 19. Box plot of AQHI values for week one of the winter sampling campaign.

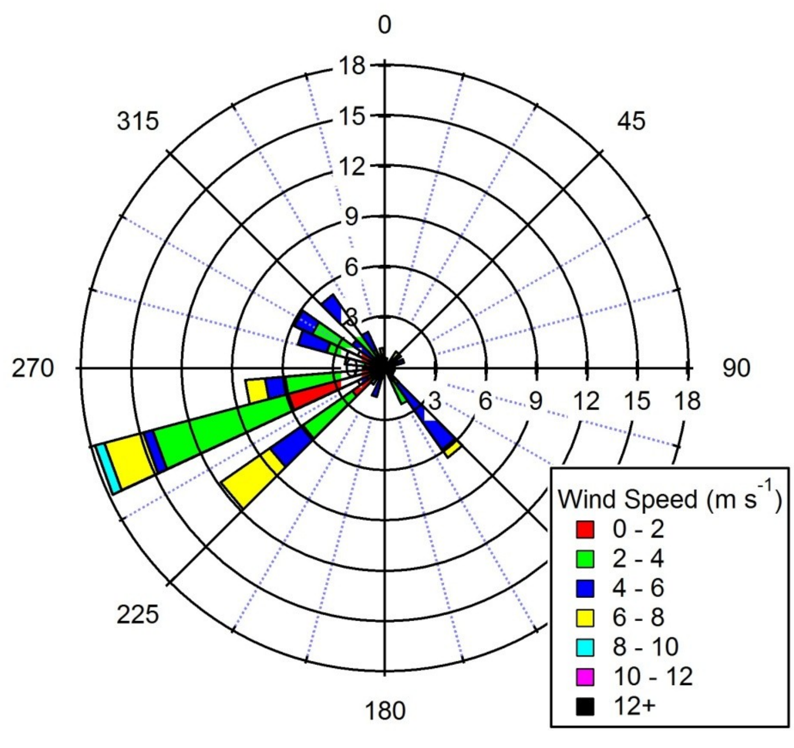


Figure 20. Wind rose of wind conditions for week one of the winter sampling campaign.

3.5 SUMMER SAMPLING CAMPAIGN

Weekly changes in AQHI values for the sample sites, NAPS site and reported AQHI are shown in Figure. 21. During the summer sampling phase of the Halifax air quality study, daily AQHI values were found to vary significantly between the reported AQHI values and the sample sites for eight out the nine sampling weeks. Nineteen individual sampling sites demonstrated a significant difference between recorded values and the reported AQHI values. Correlations between the various sample sites by sample weeks are located in Table. 6.

The locations of the sampling sites are identified by sample week in Figure. 22. Statistical information is presented in the same manner as the winter sampling campaign likewise the same time series, box plots and wind rose have been produced for each sample week. Only the first sampling week has been shown, the remainder can be found in Appendix. B. Wind condition data was gathered from Environment Canada publically available data and is for the metrological site on the Halifax Naval Dockyards (Halifax Harbour narrows).

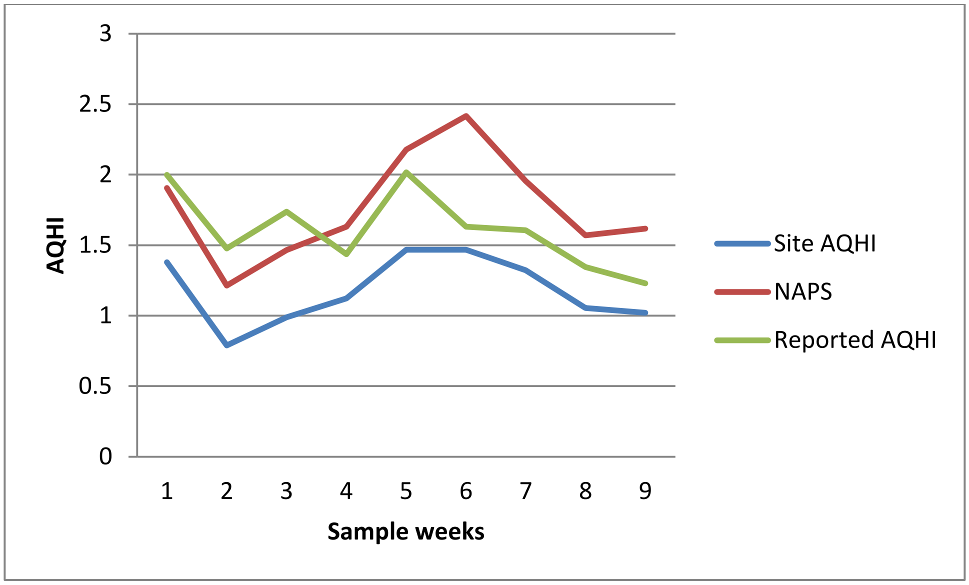


Figure 21. Weekly variation in AQHI values from the reported AQHI, NAPS site and mean site AQHI values.

Table 6. This table is a summary of linear correlations in the summer sampling campaign.

Sample week	Correlation between sites	Correlation between sites and NAPS site	Correlation between sites and reported	Correlation between NAPS and reported	Total
1	6	5	2	0	13
2	1	2	2	1	6
3	4	3	0	0	7
4	10	3	1	1	15
5	2	1	0	0	3
6	7	6	3	0	16
7	0	0	0	0	0
8	2	1	0	0	3
9	3	1	0	0	4
Total	35	22	8	2	67

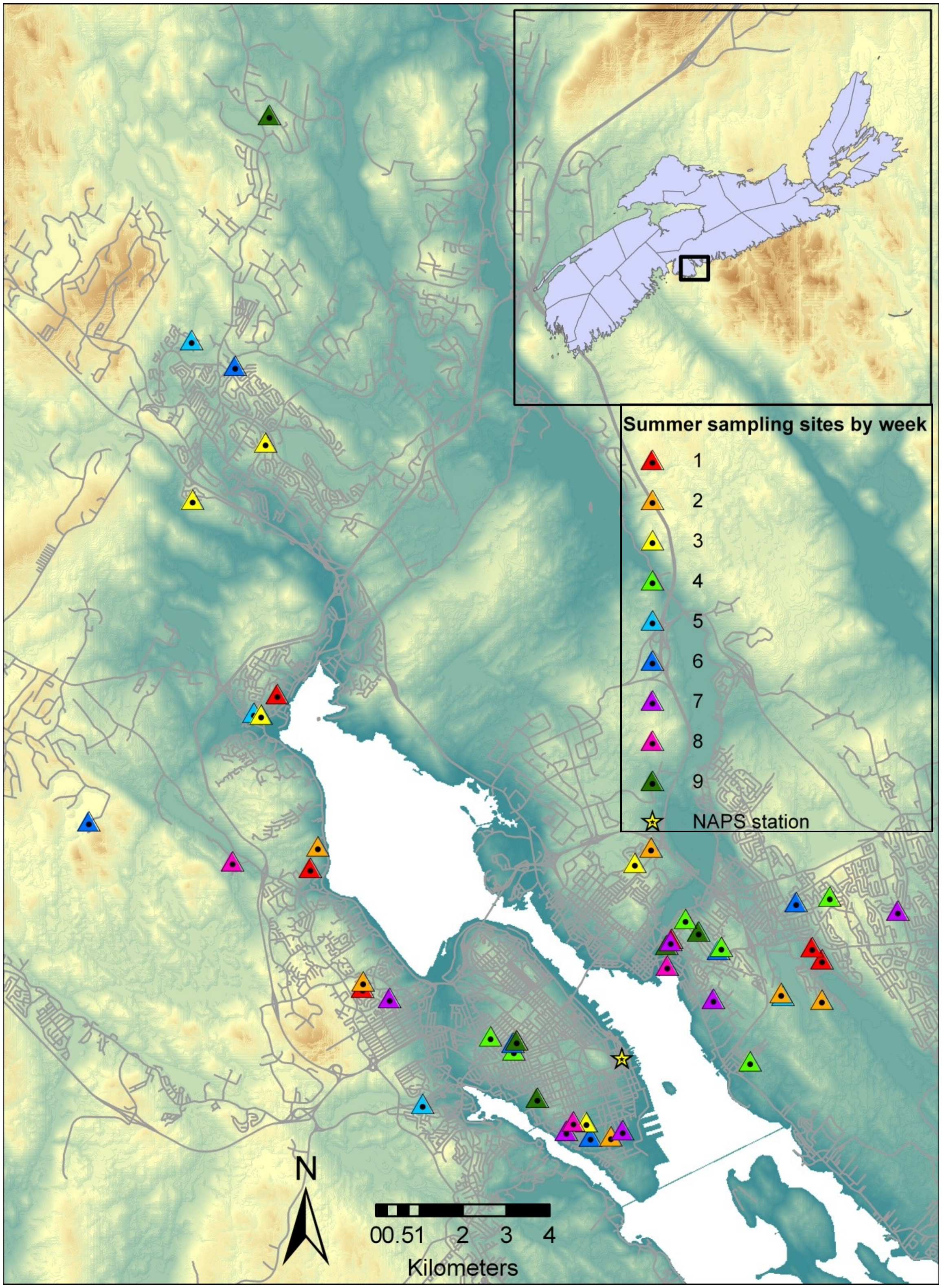


Figure 22. Sampling sites during the summer sampling campaign are shown by the week in which sampling occurred.

3.5.1 Week one, summer sampling campaign (June 18 to June 24, 2009)

Maximum and minimum AQHI values for week one of the summer sampling campaign are 2.63 and 0.9 respectively with a median of 1.52. There is one data point missing for the sample sites (site HFAX-003). The AQHI time series shows consistent AQHI levels, with values varying less than one AQHI point through the week (Figure. 23) supported by the weekly box plot (Figure. 25). AQHI deviation reflects this same pattern (Figure. 24). The weekly wind rose shows a consistent south easterly wind (Figure. 26).

The data for this sampling week passes both the normality and equal variance tests allowing for ANOVA and Tukey's Test to be uses to test variance between the sample groups. Five of the sample sites are significantly different from the reported AQHI levels. The Pearson Product Moment Correlation method was use to produce correlation coefficients:

Normality Test (Shapiro-Wilk) Passed ($P = 0.088$)
Equal Variance Test: Passed ($P = 0.057$)

Group Name	N	Missing	Mean	Std Dev	SEM
HFAX-001	7	0	1.385	0.148	0.0558
HFAX-004	7	0	1.400	0.483	0.182
HFAX-009	7	0	1.528	0.320	0.121
HFAX-030	7	0	1.296	0.389	0.147
HFAX-006	7	0	1.274	0.142	0.0537
HFAX-003	7	1	1.384	0.249	0.102
NAPS	7	0	1.906	0.416	0.157
Reported	7	0	1.998	0.280	0.106

Source of Variation	DF	SS	MS	F	P
Between Groups	7	3.753	0.536	5.052	<0.001
Residual	47	4.988	0.106		
Total	54	8.741			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P = <0.001$).

Power of performed test with alpha = 0.050: 0.975

All Pairwise Multiple Comparison Procedures (Tukey's Test):

Comparisons for factor:

Comparison	Diff of Means	p	q	P	P<0.050
Reported vs. HFAX-006	0.724	8	5.880	0.003	Yes
Reported vs. HFAX-030	0.702	8	5.699	0.005	Yes
Reported vs. HFAX-003	0.614	8	4.787	0.029	Yes
Reported vs. HFAX-001	0.612	8	4.974	0.020	Yes
Reported vs. HFAX-004	0.598	8	4.857	0.025	Yes
Reported vs. HFAX-009	0.470	8	3.818	0.148	No
Reported vs. NAPS	0.0921	8	0.748	0.999	Do Not Test
NAPS vs. HFAX-006	0.632	8	5.132	0.015	Yes
NAPS vs. HFAX-030	0.610	8	4.951	0.021	Yes
NAPS vs. HFAX-003	0.521	8	4.068	0.101	No
NAPS vs. HFAX-001	0.520	8	4.226	0.078	Do Not Test
NAPS vs. HFAX-004	0.506	8	4.109	0.094	Do Not Test
NAPS vs. HFAX-009	0.378	8	3.070	0.388	Do Not Test
HFAX-009 vs. HFAX-006	0.254	8	2.062	0.825	No
HFAX-009 vs. HFAX-030	0.232	8	1.881	0.883	Do Not Test
HFAX-009 vs. HFAX-003	0.143	8	1.119	0.993	Do Not Test
HFAX-009 vs. HFAX-001	0.142	8	1.157	0.991	Do Not Test
HFAX-009 vs. HFAX-004	0.128	8	1.040	0.995	Do Not Test
HFAX-004 vs. HFAX-006	0.126	8	1.022	0.996	Do Not Test
HFAX-004 vs. HFAX-030	0.104	8	0.841	0.999	Do Not Test
HFAX-004 vs. HFAX-003	0.0154	8	0.120	1.000	Do Not Test
HFAX-004 vs. HFAX-001	0.0144	8	0.117	1.000	Do Not Test
HFAX-001 vs. HFAX-006	0.112	8	0.906	0.998	Do Not Test
HFAX-001 vs. HFAX-030	0.0892	8	0.724	1.000	Do Not Test
HFAX-001 vs. HFAX-003	0.00102	8	0.00793	1.000	Do Not Test
HFAX-003 vs. HFAX-006	0.110	8	0.862	0.999	Do Not Test
HFAX-003 vs. HFAX-030	0.0882	8	0.688	1.000	Do Not Test
HFAX-030 vs. HFAX-006	0.0223	8	0.181	1.000	Do Not Test

Pearson Product Moment Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-004	**HFAX-009**	**HFAX-030**	**HFAX-006**	**HFAX-003**	**NAPS**	**Reported**
HFAX-001	-0.100	0.528	0.007	0.775	0.281	0.472	0.448
	0.831	0.223	0.988	0.041	0.590	0.285	0.313
	7	7	7	7	6	7	7
HFAX-004		0.644	0.942	0.397	0.969	0.630	-0.789
		0.119	0.002	0.379	0.001	0.130	0.035
		7	7	7	6	7	7
HFAX-009			0.811	0.921	0.676	0.964	-0.377
			0.027	0.003	0.140	0.000	0.404
			7	7	6	7	7
HFAX-030				0.568	0.892	0.776	-0.732
				0.183	0.017	0.040	0.062
				7	6	7	7
HFAX-006					0.593	0.901	-0.0603
					0.215	0.006	0.898
					6	7	7
HFAX-003						0.668	-0.840
						0.147	0.037
						6	6
NAPS							-0.465
							0.293
							7

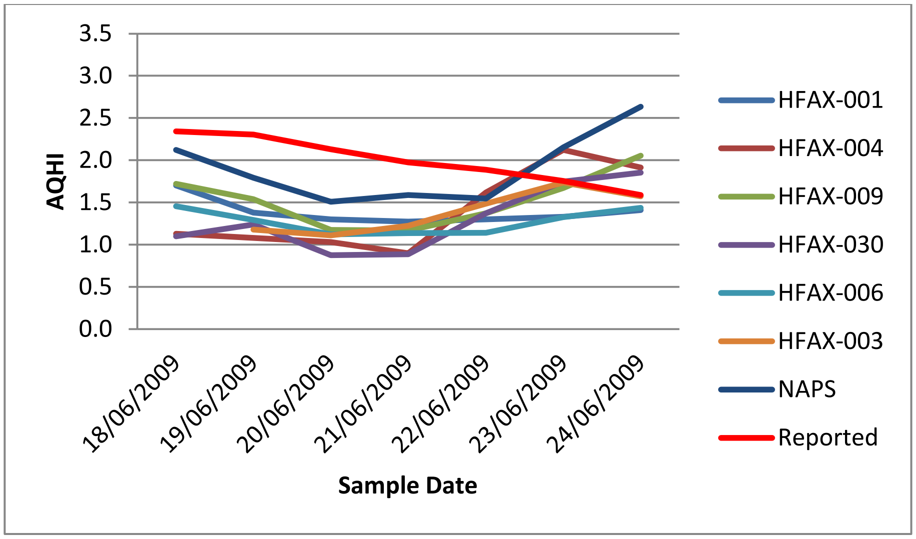


Figure 23. Time series of AQHI values for week one of the summer sampling season.

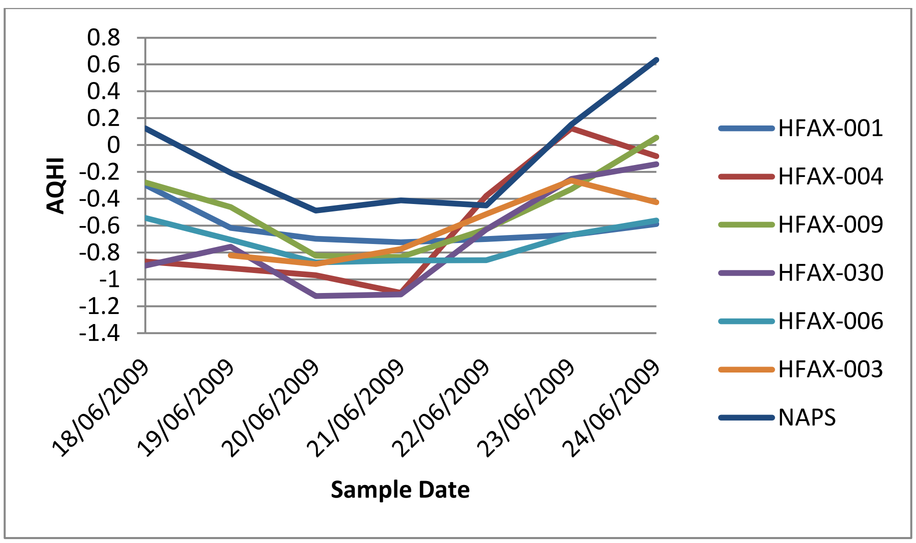


Figure 24. Time series of deviation from the normalized reported AQHI values.

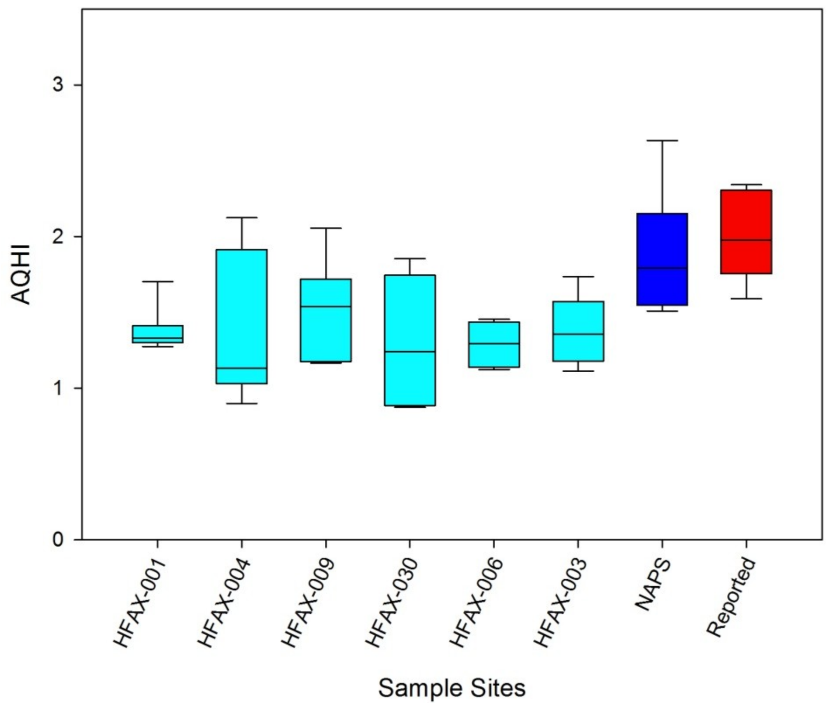


Figure 25. Box plot of AQHI values for sample week one of the summer sampling campaign.

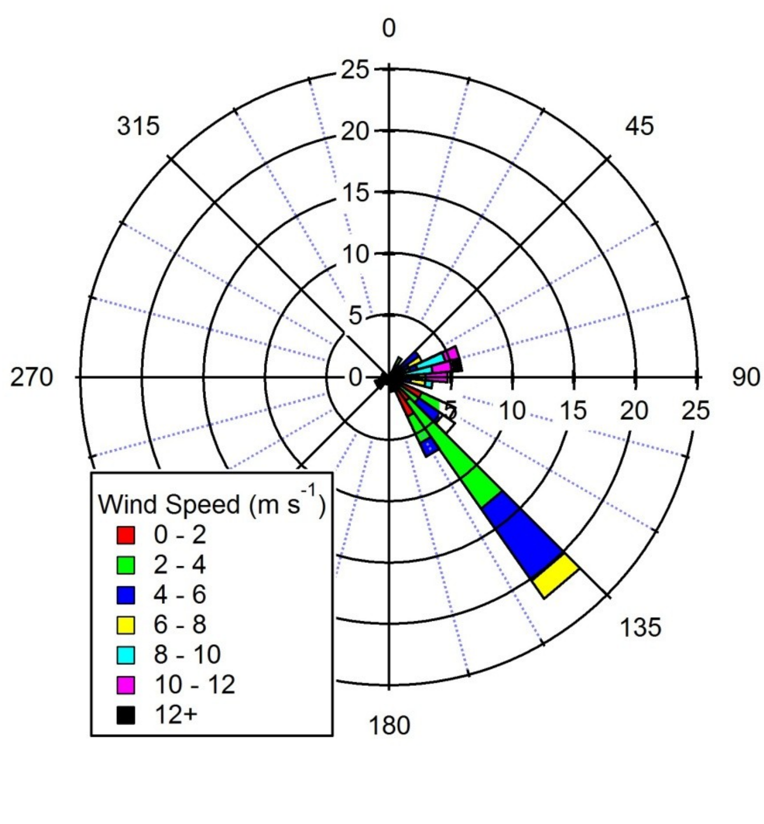


Figure 26. Wind rose of the wind conditions for sample week one of the summer sampling campaign.

3.6 MATCHED SAMPLE SITES

42 sample sites out the winter sampling campaign were re-sampled during the summer sampling campaign (the remainder changed due to dropout and new recruitment). Using these 42 sites the two different seasonal sampling campaigns can be compared with improved clarity. Table. 7 provides the descriptive statistics for the two seasons contributing AQHI pollutants, while Figure. 27 provides box plots of the pollutants and Mann Whitney Rank Sum Test results comparing between the two seasons. Both NO_2 and O_3 show statistically significant differences while $PM_{2.5}$ is not significantly different between the sampling campaigns.

Table 7. Descriptive statistics for the three AQHI pollutants and AQHI values for the matched winter and summer sample sites.

	Pollutant	Sample Size	Maximum	Minimum	Median	Range	Standard Deviation	Skewness	Kurtosis
Winter season	NO_2 (ppb)	344	26.3	0.7	5.7	25.6	4.8	1.2	1.5
	0_3 (ppb)	344	33.7	19.1	27.0	14.6	3.3	-0.2	-0.5
	$PM_{2.5}$ (μg m^{-3})	344	19.8	0.1	4.9	19.7	3.4	0.9	1.1
	AQHI	344	4.4	1.3	2.1	3.2	0.5	1.3	2.3
Summer season	NO_2 (ppb)	342	18.3	0.6	2.1	17.7	3.3	1.9	5.3
	0_3 (ppb)	342	22.6	5.2	12.4	17.5	3.6	0.0	0.0
	$PM_{2.5}$ (μg m^{-3})	342	24.4	0.1	5.2	24.2	3.8	1.3	1.8
	AQHI	342	3.1	0.4	1.2	2.7	0.4	1.3	2.3

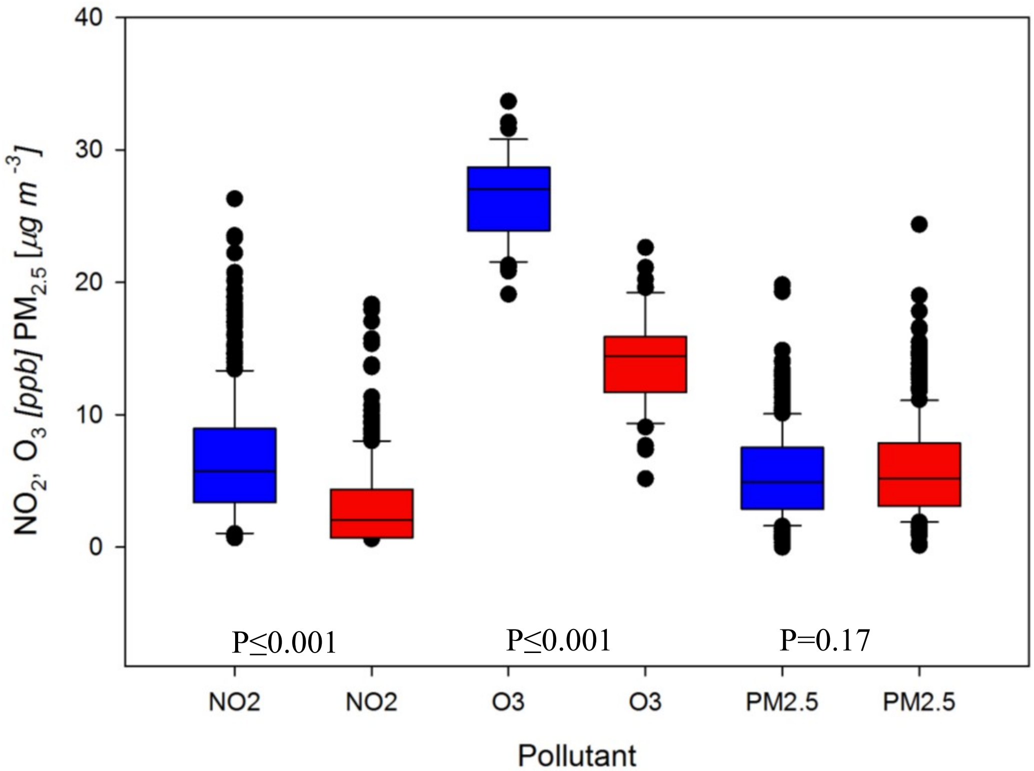


Figure 27. Box plot of the three AQHI pollutant compared by season, winter (blue) and summer (red).

The AQHI values (Figure. 28) were tested using a paired T-test demonstrating a clear statistical difference between the two seasons at the matched sample sites (P=<0.001):

Normality Test (Shapiro-Wilk) Passed (P = 0.980)

Treatment Name	N	Mean	Std Dev
Phase one	42	2.109	0.172
Phase two	42	1.180	0.255
Difference	42	0.929	0.342

t = 17.597 with 41 degrees of freedom. (P = <0.001)

95 percent confidence interval for difference of means: 0.822 to 1.036

The change that occurred with the treatment is greater than would be expected by chance; there is a statistically significant change (P ≤0.001)

Power of performed test with alpha = 0.050: 1.000

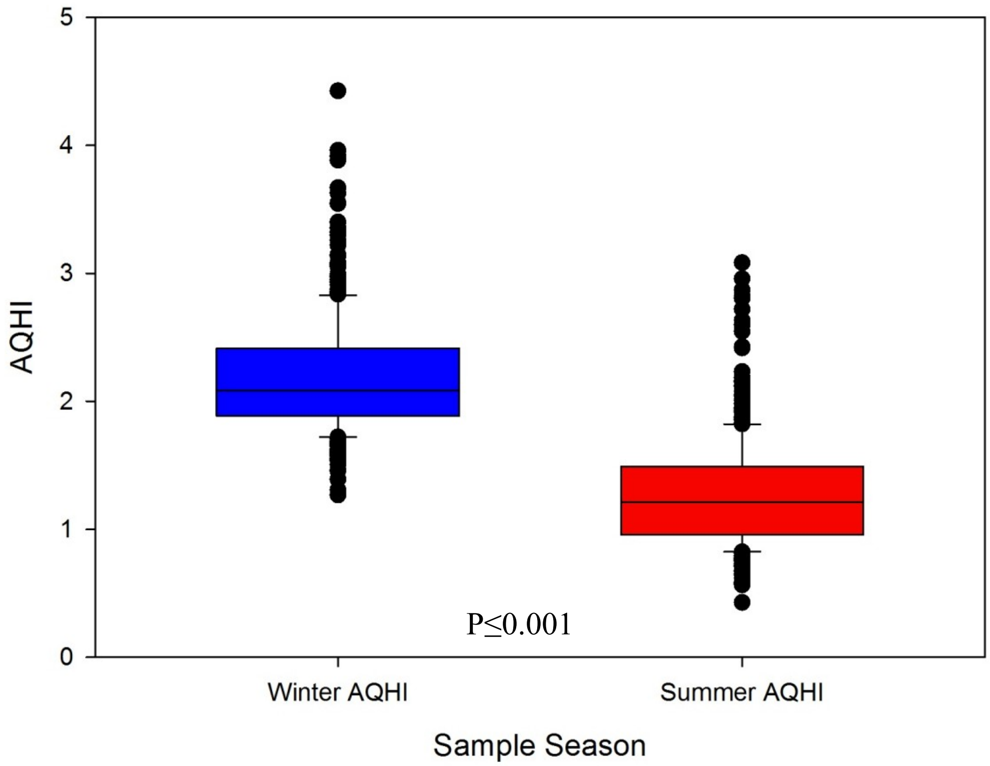


Figure 28. Weekly AQHI values from the matched 42 sample sites, tested using a Paired T-test.

3.7 SPATIAL ANALYSIS

Natural neighbours interpolation of the seasonal AQHI pollutants are shown in Figures 29 to 31. These Figures describe the overall pollutant distribution of the three components of the AQHI and demonstrate the spatial variation of the individual components. It is important to note that is a space-filling algorithm produces an interpolated layer not a predictive model of the region. Descriptive statistics of the individual pollutants are tabulated in Table. 8.

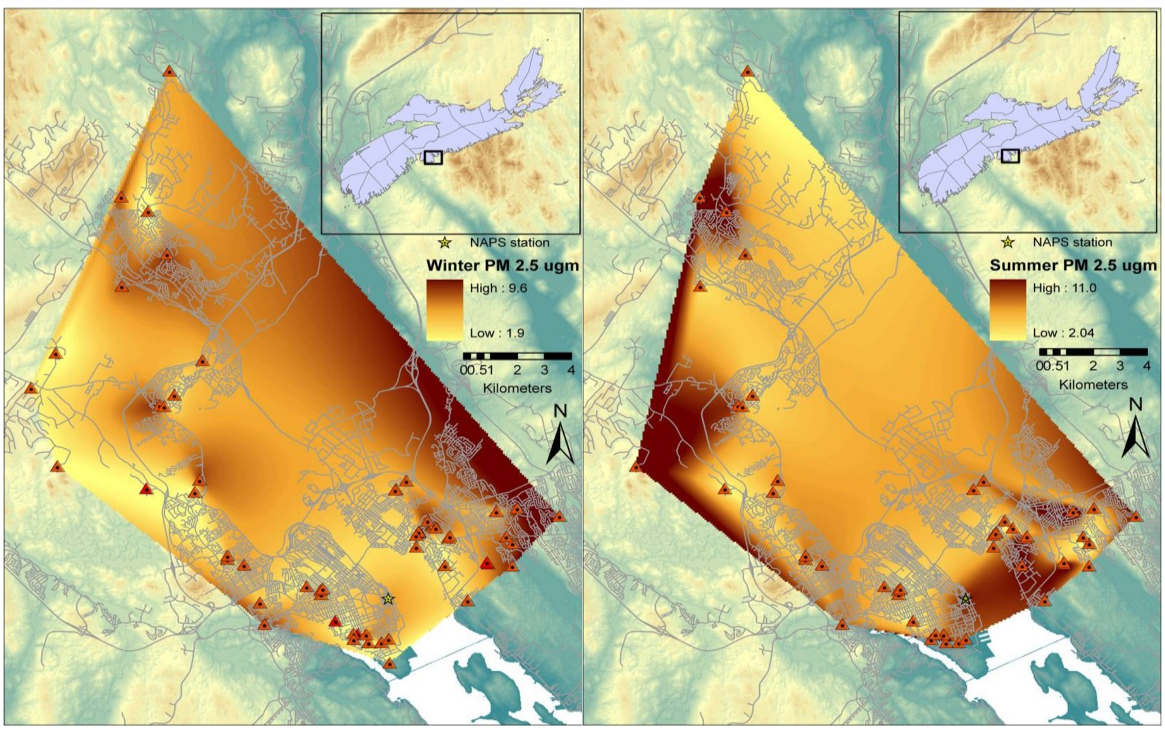


Figure 29. Natural Neighbours interpolation of $PM_{2.5}$ µg m^{-3} across the Halifax urban region for the winter (left) and summer (right) sampling campaigns.

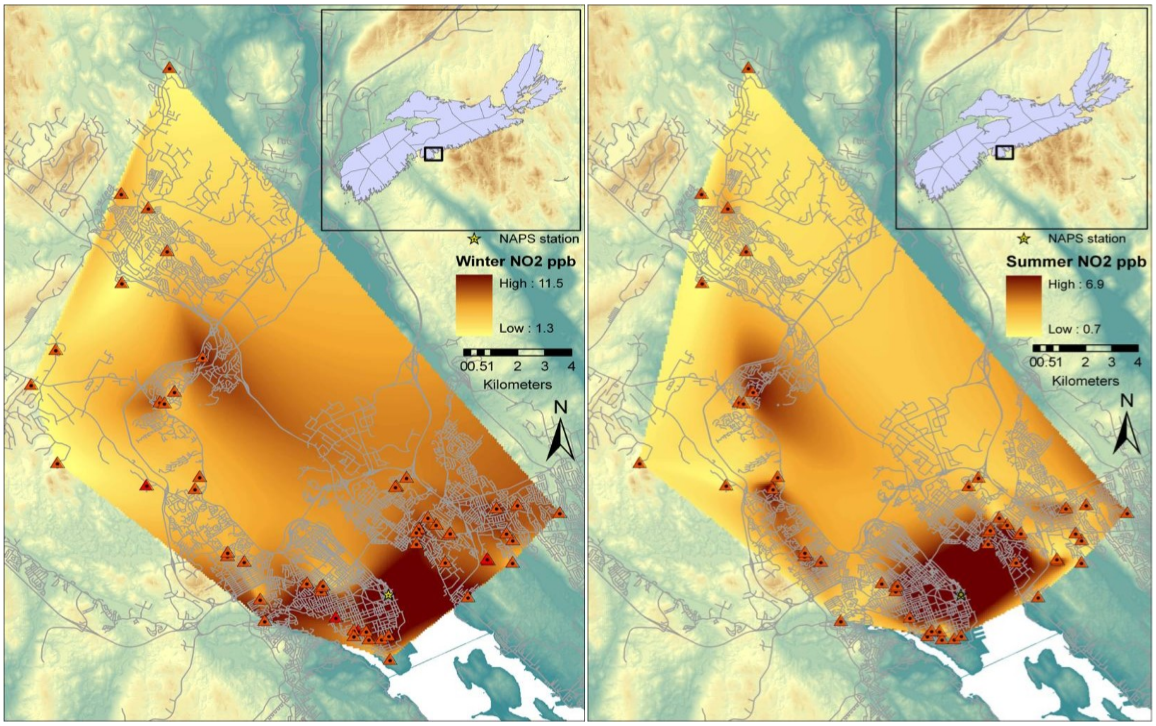


Figure 30. Natural Neighbours interpolation of the NO_2 (ppb) across the Halifax urban region for the winter (left) and summer (right) sampling campaigns.

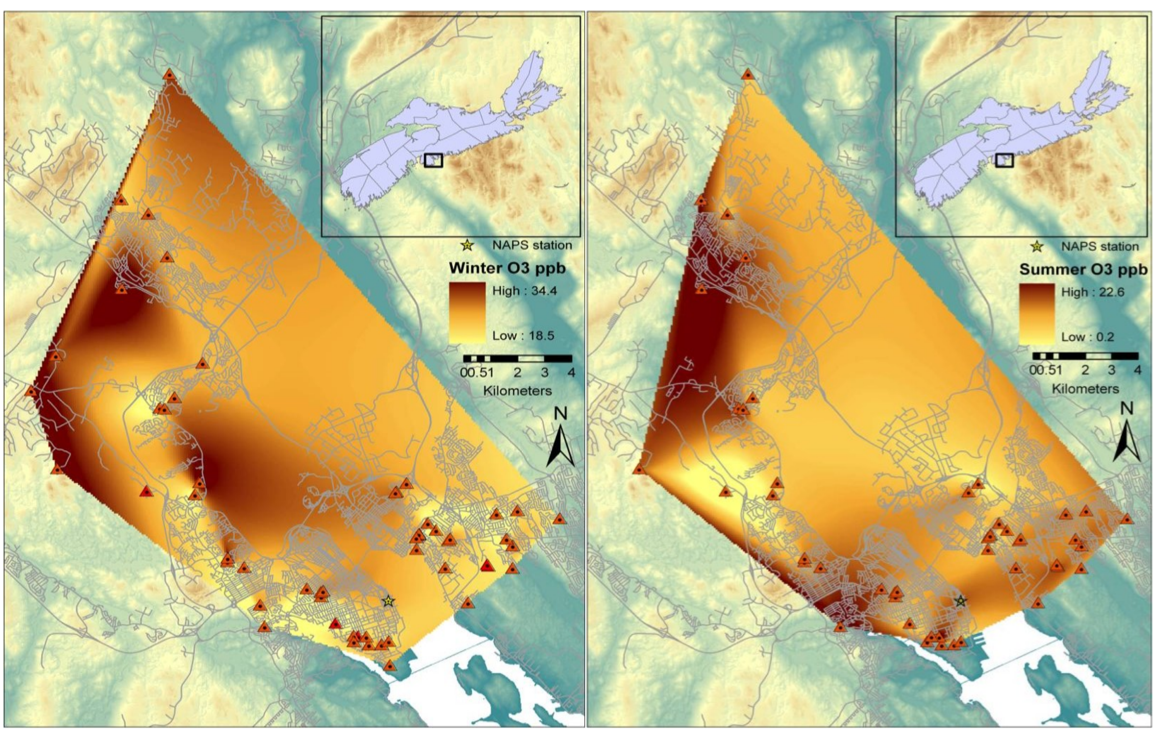


Figure 31. Natural Neighbours interpolation of O_3 (ppb) across the Halifax urban region for the winter (left) and summer (right) sampling campaigns.

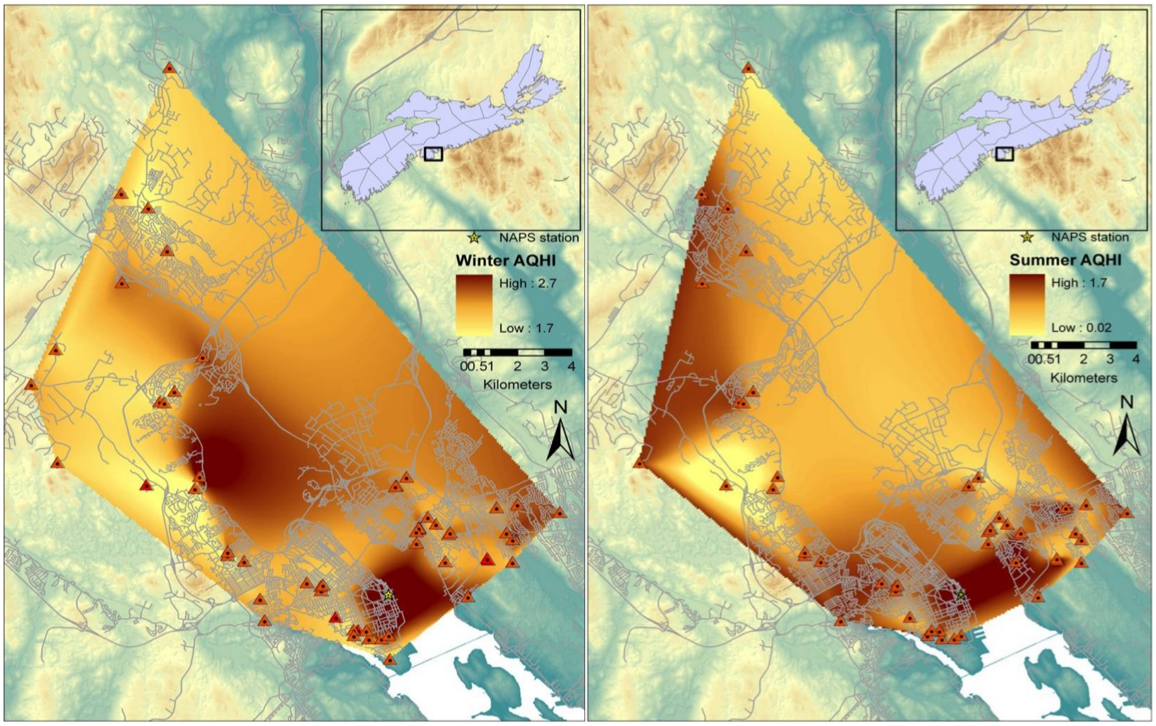


Figure 32. Spatial interpolations of winter (left) and summer (right) AQHI values as calculated from the distributed sample sites and the NAPS station.

Table 8. Descriptive statistics of the three components (NO_2, 0_3, $PM_{2.5}$) of the AQHI for both winter and summer sampling campaigns for all sample sites.

	Pollutant	Sample Size	Maximum	Minimum	Median	Range	Standard Deviation	Skewness	Kurtosis
Winter season	NO_2 (ppb)	398	26.30	0.70	5.42	25.60	4.75	1.214	1.49
	0_3 (ppb)	398	43.03	12.51	26.58	30.52	5.22	0.21	-0.32
	$PM_{2.5}$ (u gm^{-3})	398	19.81	0.13	4.80	19.68	3.26	0.97	1.30
Summer season	NO_2 (ppb)	392	18.34	0.64	2.17	17.70	3.183	1.85	4.17
	0_3 (ppb)	392	22.62	5.17	13.85	17.45	3.502	0.11	0.00
	$PM_{2.5}$ (u gm^{-3})	392	24.37	0.14	4.97	24.23	3.74	1.29	2.00

3.8 CROSS TABULATED AQHI VALUES

In order to more accurately reproduce the AQHI as it would be reported to the public and to assess variation from the reported values. Cross tabulatulations were calculated for sample sites vs NAPS and samples vs reported AQHI values in and by sample day. This data is presented in Figures 33 through 36 by season and percent of non-agreement between the daily reported AQHI and the site AQHI. In Figures 33 and 34 winter and summer respectively, the reported AQHI is presented as the red line, and the percent of samples sites for any given sample day which disagree with that reported AQHI are presented as the blue fill. Across the seasons there is a trend of higher agreement on days will lower AQHI values and greater disagreement when the AQHI is higher. In Figures 35 and 36 the percent disagreement is mapped spatially by the sample week in colour and the percent disagreement in the shape of the sample point.

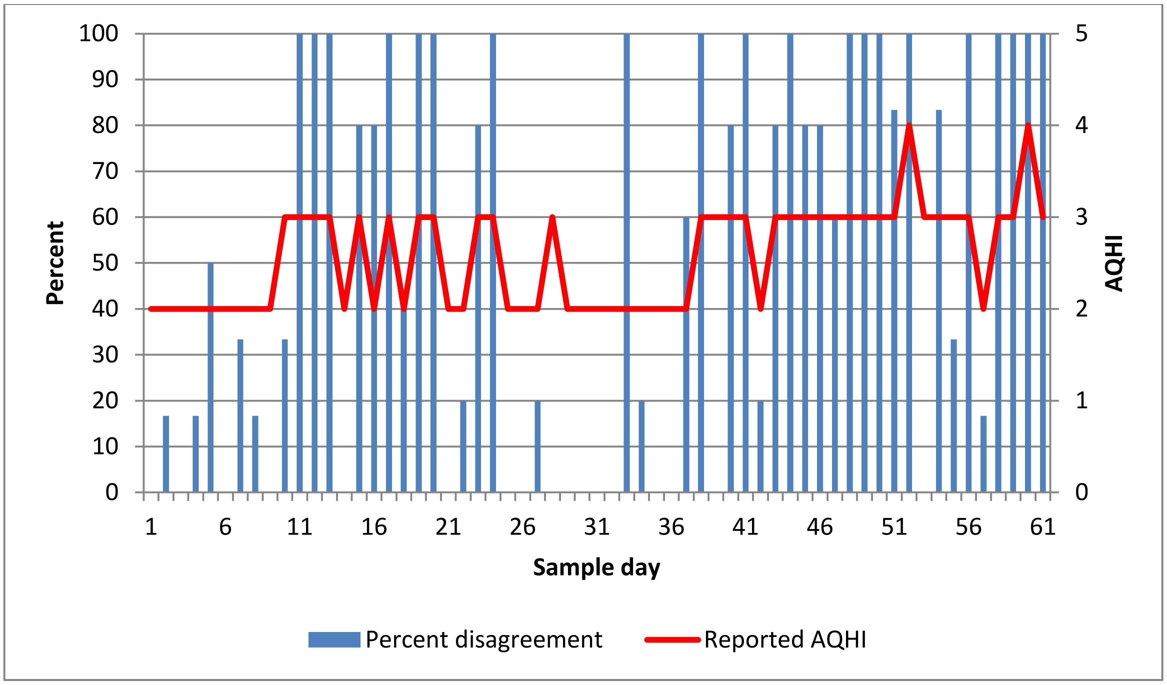


Figure 33. Time series of the winter sampling campaign, showing the reported AQHI in red and the percent disagreement of the sample sites in blue bars.

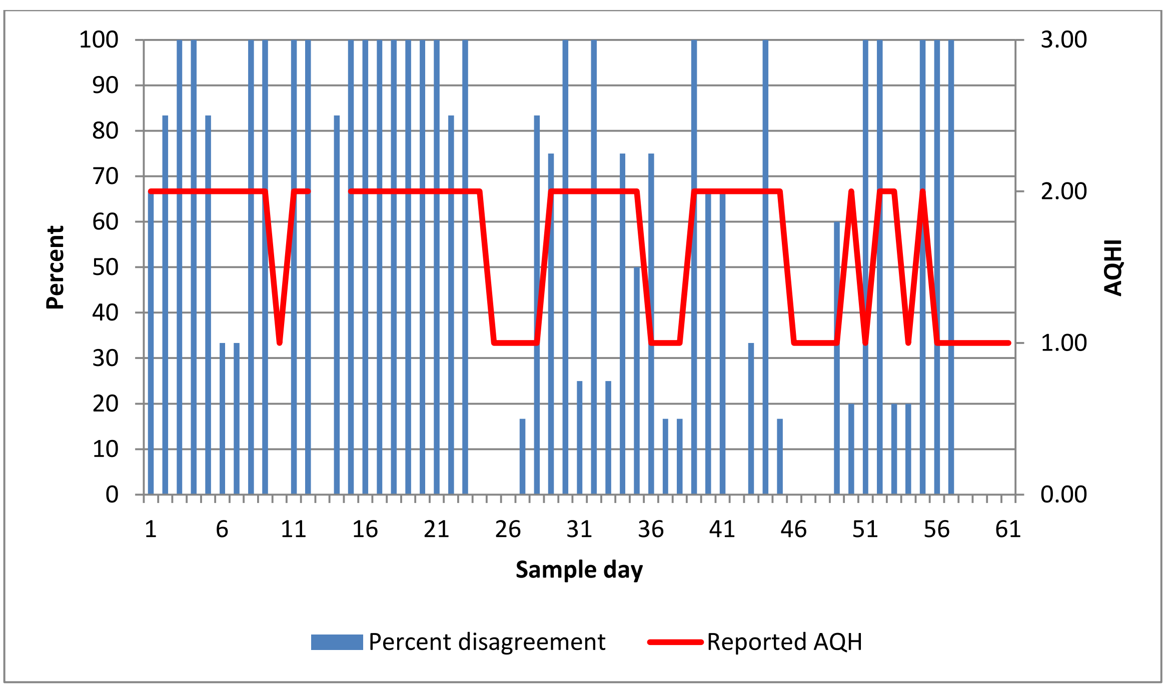


Figure 34. Time series of the summer sampling campaign, showing the reported AHI in red and the percent disagreement of the sample sites in blue bars.

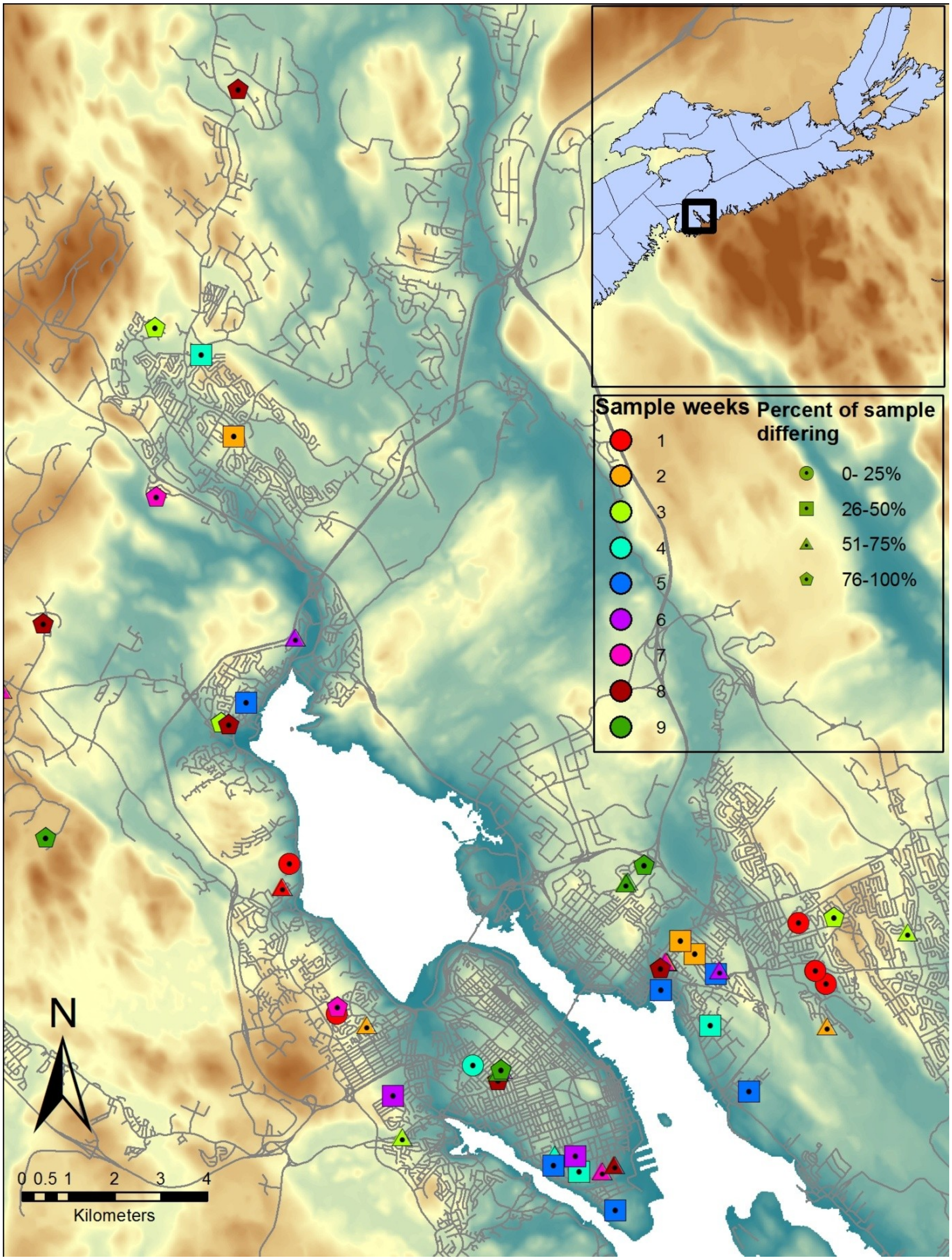


Figure 35. This figure shows the percent of non-agreement of rounded AQHI values between the sample sites and the reported AQHI for the winter sampling campaign. The colours denote the sample weeks.

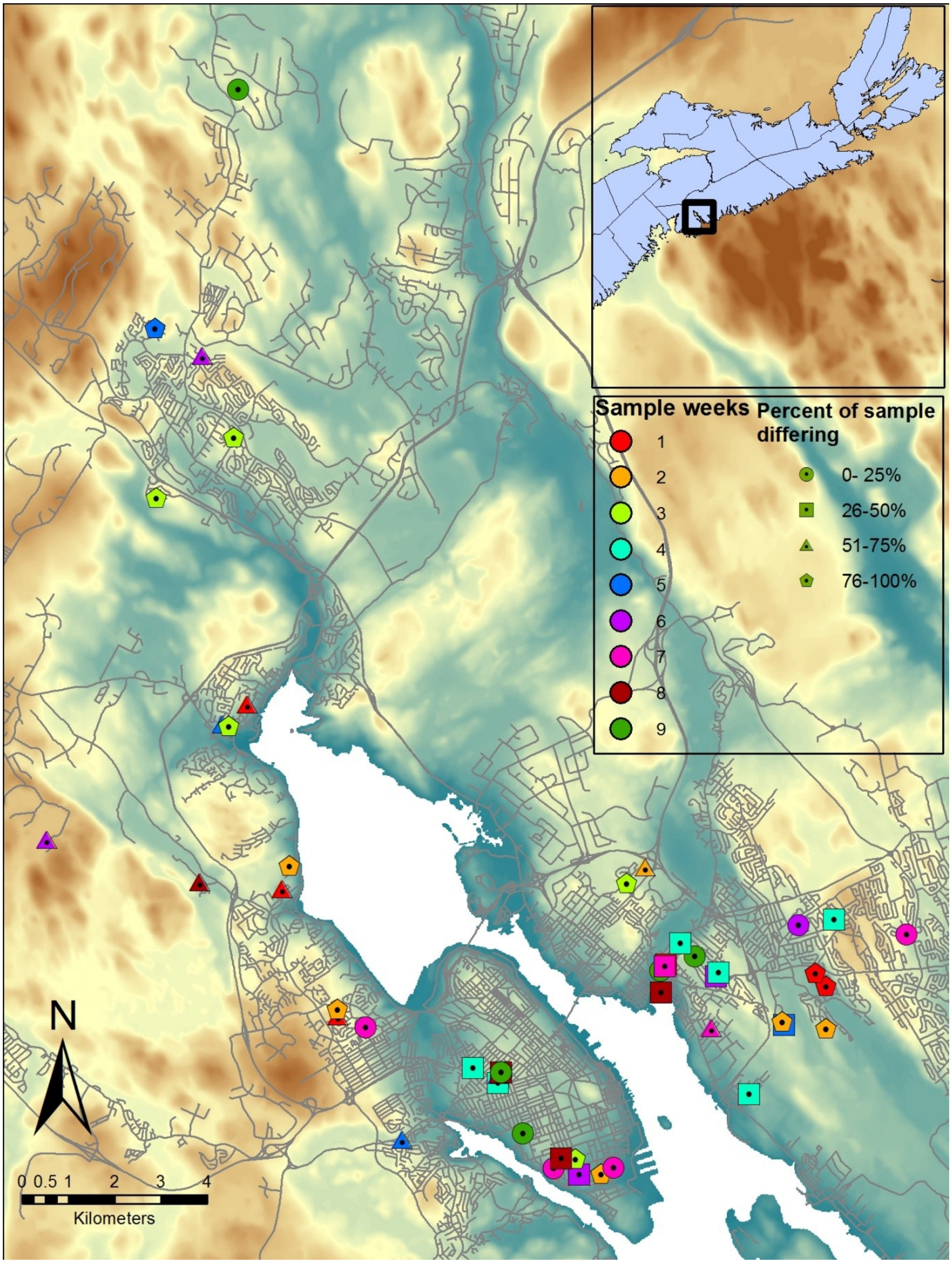


Figure 36. This figure shows the percent of non-agreement of rounded AQHI values between the sample sites and the reported AQHI in the summer sampling campaign. The colours denote the sample weeks.

CHAPTER 4.0 DISCUSSION

Four objectives were identified for this study as an effective way to address the gap in our understanding of air quality in the city of Halifax, its spatiotemporal variation over urban spatial scales and the representativeness of the AQHI as an air quality population risk assessment tool. A number of statistical tests and modeling approaches were used to address the four aims: (i) to develop a unique AQHI value for each sample site, (ii) to assess the seasonal and intra-site variation in AQHI values, (iii) to compare the AQHI values to the reported AQHI value, and (iv) to develop spatial interpolations of the AQHI pollutants and values to better understand the geographic distribution of the pollutants, and the AQHI across the Halifax urban region. The results of this analysis are discussed in this chapter.

For each sample site a unique AQHI was developed for each sample day, this was calculated using the method previously described in Equation 1. This formula was also used for the NAPS site AQHI values, producing AQHI values ranging from 0.49 to a maximum of 4.42 spanning both the winter and summer season sampling campaigns and includes all sampling points. The two seasonal sampling campaigns were then assessed in greater detail, first by investigating the temporal variation over the campaign in weekly and daily increments. Spatial differences of the AQHI were then explored by looking at each sample week and the individual sample sites. This data was then compared with the reported Environment Canada AQHI to better understand the variation of the data set with respect to the reported values. A secondary analysis was conducted using whole AQHI numbers in the same manner as the AQHI would be reported to the public in order to assess the variation with respect to this reporting method. Spatial analysis was also conducted using ArcGIS to explore the differences in AQHI values and its component pollutants across the urban region to gain a better conceptual and visual model of the spatial distribution.

4.1 WINTER SAMPLING CAMPAIGN

During the winter sampling campaign little temporal variation was observed in the mean weekly AQHI values across the sample sites. The mean weekly AQHI was 2.1 with an IQR of 1.84 to 2.32 for the full sampling season (Figure. 10 and Table. 3). Using a finer temporal resolution, that included the mean daily values at each sample site, a more distinct pattern of peaks and troughs through the sampling campaign were observed (Figure. 8). When this data is reduced into weekly samples and individual sample sites several salient features can be noted.

Firstly, there appears to be a similar pattern of daily variation of the measured AQHI across most of the sample sites. However, some weeks (weeks 4 and 7) show much more mixed variation in AQHI values across all of the sites. These two weeks are also unusual from a meteorological perspective; as both weeks show a strong northwest – southwest bi-modal wind pattern, which is different from other weeks in the sampling campaign. This demonstrates the impact of meteorological conditions on air quality in the region. For example, as the winds change the geography of the region funnels the wind in a different manner which changes pollutants patterns moving pollutants in a different direction, either toward or away from receptors. Secondly, there tends to be little statistical difference between the sample sites, as distributed around the city. Only seven of the 50 sites demonstrated a significant difference in relation to the reported AQHI, indicating that there is little spatial variation in AQHI levels across the region.

To test how well the reported AQHI reflects that of site specific AQHI values from around the city, the data was divided into three bins: the reported AQHI, the AQHI from the 50 sample sites and the NAPS site AQHI values. The NAPS site has been considered different from the sample sites as it was sampled throughout the complete sampling campaign and is not a residential location. The AQHI data was tested using the Kruskal-Walls ANOVA on Ranks and Dunn’s method for multiple comparisons (KW-Dunn). The KW-Dunn test demonstrated that the reported AQHI is significantly different from that of the AQHI values from the 50 sampling sites but not from that of the NAPS site (Figure. 10). This analysis also demonstrates that the reported AQHI is over reporting when compared to the 50 sites AQHI in the Halifax region during the winter by approximately 0.5 of an AQHI point. One hypothesis for the over reporting is that the Lake Major AQHI data is very similar to that of the 50 reporting sites around the city and when combined with the AQHI from the downtown NAPS site the value is elevated above the other sample sites. Unfortunately without access to the Lake Major data, which is unavailable due to an NAPS internal audit for the 2009 period, it is not possible to validate this.

4.2 SUMMER SAMPLING CAMPAIGN

The temporal variation in the AQHI values at the 50 sites over the nine-week sampling period in the summer campaign was very similar to that of the winter campaign. The AQHI hovered around a value of 1.20 with an IQR 0.93 to 1.4 which is slightly lower than that of the winter (the seasonal variation with be discussed in a later section) (Figure. 11 and Table. 3). Using a finer temporal resolution of mean AQHI per sample day, a similar pattern of daily peaks and troughs can be observed with the same amount of variation as is seen during the winter sampling campaign (Figure. 8). This identifies a continual cyclical pattern of AQHI rise and fall through the year on, at the least, a day-to-day timeframe. This variation could be related to various inputs to the pollutant budget in the region including vehicle density changes or variations in O_3 photochemistry driven by meteorological factors.

The comparison between the reported AQHI and the sample AQHI for the summer season was tested using the KW-Dunn test. Results demonstrated that the reported AQHI was not statistically different from the NAPS site values. However it was significantly higher than the sample site AQHI values (Figure. 11). This is an important finding because it demonstrates that the AQHI is over reporting to the public for both seasons and is therefore over reporting the amount of air pollution that the population may be experiencing. This could have impacts on the accuracy of exposure studies or epidemiology studies of the common effects of poor air quality such as COPD, or asthma which use the reported AQHI as a proxy for air pollution exposure. In Halifax, with its low levels of air pollution, these differences may not be of relative health concern. However, over a lifetime or if the overall level of AQHI becomes elevated as a result of population or industry changes, this could be of larger epidemiological concern. Outside Halifax – if the same pattern holds true across other urban centres – this could represent a significant over reporting of air pollution exposure.

When the data from the summer campaign is reduced by sample site and by sample week, differences from the winter sampling campaign emerges. There is higher variation in the summer AQHI values than during the winter. There was significant variance in the reported AQHI values from the site AQHI during eight of the nine weeks and 19 individual sites were found to be significantly different (p=0.05) from the reported AQHI. Likewise, there is less co-linear variation within the sample sites, NAPS site and the reported AQHI as demonstrated in Table. 6.

CO-VARIATION OF SITES

Pearson Product Moment and Spearman Rank Order Correlation calculations were used to investigate the co-variation between the sample sites, NAPS site and reported AQHI for each sample week for both sampling campaigns. For this analysis the data was compared as a pair of daily AQHI values from two sites over the sample week (sample sites, NAPS site or reported AQHI). For example, a week with six sample sites and both NAPS site values and reported AQHI values would have a possible 15 possible co-varying sample site pairs, six possible NAPS site and reported AQHI pairs and one possible pair between the NAPS site and reported AQHI.

During the winter sampling campaign, 27% of the total pairs co-varied while in the summer campaign it was found to be 25%, a near identical number. However, the sources of these numbers were different between the two campaigns. During the winter sampling campaign 41% of the possible sample site pairs demonstrated co-variation, with 26% co-variation between the sample sites and the NAPS site and 22% with the reported AQHI. There was no co-variation between the NAPS site and reported AQHI values. In contrast, during the summer campaign, 32% of the possible sample site pairs co-varied with 44% co-variation between the sample sites and the NAPS site and 16% with the reported AQHI. The NAPS and reported sites varied for 22% during the summer sampling campaign.

The changing patterns of co-variation suggest differing fluxes of air pollution across the region between the two seasons. In the winter agreement between the sample sites is higher and agreement with the NAPS site is low, while in the summer agreement is higher between the sites and the NAPS values and slightly lower between the sites. There is low agreement between the sample sites and NAPS site verses the reported AQHI during both seasons. This suggests that in the winter the downtown core (where the NAPS site is located) has different micrometeorology, and air pollution features than observed in the rest of city and that this difference is not so apparent in the summer. A possible answer for the variation could be the pollutant mix which controls AQHI. In the winter NO_2 forces the deviation in AQHI levels between the sample sites and NAPS site, which could be the result of different traffic patterns- slower driving in the winter with more idling or as a result increased NO_2 production from fossil fuel combustion used for heating which would be more concentrated in the downtown core. Or from the colder stiller winter air over night creating local temperature inversions and trapping the both NO_2 and $PM_{2.5}$ closer to the ground.

The low co-variation between both the sample sites and NAPS site data with the reported AQHI indicates a different pollution profile between the reported AQHI and the city air pollution. A different pattern of AQHI values changes suggests that the reported AQHI is changing differently than either the NAPS site or the sample sites and it is responding to different drivers. Which suggests that the statistical similarities in AQHI values between the sample sites and the reported AQHI are more a result of the low levels of air pollution in the region rather than the reported AQHI accurately reflecting the local air pollution patterns in the region during the winter.

4.3 Seasonal comparison

To compare the two sampling campaigns the sampling data was restricted to the 42 sites that had been sampled during both monitoring campaigns. They were tested using a paired T-test and where found to vary significantly ($P \leq 0.001$) between the two campaigns and therefore the two seasons (Figure. 28). The difference in real AQHI measurements between the two seasons was approximately one with a 95% confidence interval of 0.82 to 1.04. While this is not a great difference in terms of population health impact at the low levels of air pollution in Halifax it does demonstrate that the air quality is poorer in the winter. To better understand what drives this variation, the individual pollutants which make up the AQHI were tested separately, as can be seen in Table 7 and Figure 27. The variation of the AQHI between the two sampling campaigns are driven by two pollutants – NO_2 and O_3 which are significantly higher ($P<0.001$) in the winter than in the summer. The drivers behind the elevated levels will be discussed in following sections.

4.4 METEOROLOGICAL VARIATION

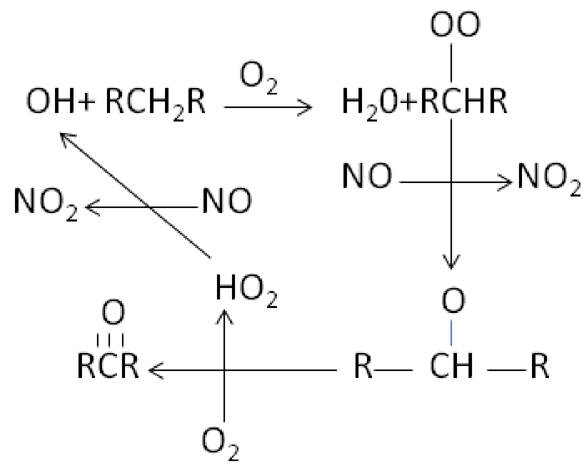
The significant variation found between seasons and between sites is driven by the variation in the $PM_{2.5}$, NO_2 and O_3 concentrations that are used to calculate the AQHI. As previously stated there are significant differences in both NO_2 and O_3 between the sample sites and between the seasonal sampling campaigns. This variation is well documented with higher daily-to-monthly integrated O_3 values being reported during the winter(20). NO_x is a high temperature combustion product resulting from vehicle traffic and residential heating and is a precursor in the formation of O_3 through the photo-chemically reversible equation (2a/2b) seen below. The nitric monoxide (NO) that is initially emitted during combustion, reacts with O_3 (titrates) O_3 which completes the cycle of O_3 formation and destruction. In un-polluted air, this creates a simple diurnal cycle that generates a small amount of excess (9,74,75).

$$NO + O_3 \rightarrow O_2 + NO_2 \qquad (2a)$$

$$NO_2 + hv \rightarrow NO + O_3 \qquad (2b)$$

Where hv is a photon of solar radiation

However, when VOC's are present in the atmosphere, an excess of O_3 is formed following the more complex chemical pathway demonstrated in equation 3 (9):



(3)

Where R is a radical of the alkyl group.

This is the formation process of long range photochemical that forms downwind of cities. Thus, changes in the concentration of O_3 precursors, NOx, VOCs, temperature and sunlight all have a role to play in observed individual concentrations of $PM_{2.5}$, NO_2 and O_3 that is seen in Halifax in the winter and summer(9,76).

Vegetation also plays a role in the levels of O_3 between the two seasons. In the winter snow cover reduces the reactive surface area and increases the passage of photons due to light reflection from the snow, thus increasing the mean O_3 concentrations(20). A second impact of increased vegetation during the summer is the effect of the stomata of the vegetation (located in leaf tissues) to absorb O_3 from the atmosphere as well as increasing the amount of reactive surface available(77). As well, during the winter some pollutants, including Peroxyacetyl nitrate (PAN) and CO, form a pollutant reservoir which is used up in a photochemical reaction in the spring forming what is known as the spring O_3 max (20). This pollutant reservoir does not build up during the summer because there are more photons and warmer temperatures and while PAN is a health irritant in its own right, in the context of AQHI it is an important precursor in the production of GLO (20,78).

The presence of vegetation may also be related to the development of microenvironments that would affect local environments and could help to explain why the AQHI is less uniform across the Halifax region in the summer when compared to the winter. As shown in Figures 35 and 36 there can be differences in the AQHI level between sites quite close to each other. These differences could be the result of microenvironments which surround the different points. These environments are the result of local factors such as strong point sources (demonstrated in the interpolation maps, Figures 29 to 32) distance from roads as well as street canyoning effects and vegetation growth. A hypothesis for the increased variability between sample sites in the summer is that vegetation forms a barrier to pollutants which is not there during the winter, in effect, the plants – trees and hedges are forming walls which impede the movement of pollutants(74). This can be demonstrated for O_3 as described above by stomatal flux but a similar mechanism has been identified for NO_2 particularly with traffic derived NO_2 (79,80). This suggests that good zoning and planning regulations could use the filtration of pollutants by properly placed vegetation barriers to provide a cleaner and more healthy atmospheric environment for the public by walling traffic pollution away from people as well as providing cleaner atmospheric area greens spaces for exercise.

A secondary influence on the levels of pollutants could be variation in seasonal wind conditions and other meteorological variation. In the winter, temperatures are lower as is the dew point (Mann-Whitney Rank Sum Test, $P \leq 0.001$), however relative humidity and precipitation are the same. For wind, the winter has statistically higher wind speeds

(Mann-Whitney Rank Sum Test, P≤0.001), with a more distributed wind dominated by a strong south westerly component, which could be bringing in long range pollution from the north eastern USA or from the Windsor-Quebec corridor(20).

The summer on the other hand has primarily a south easterly wind, which could bring in cargo or cruise ship emissions from the various docks located in Halifax Harbour inland into the residential heart of Halifax. While in the winter these emissions would be more likely pushed out over the ocean by the south westerly wind. However there is potential for marine inversions to recycle the air pollution back onto land as cool air above the marine environment shifts landward as the warmer terrestrial air rises (81).The variation in wind direction could influence the addition of air pollution from outside the urban area, but in the summer could also add in an ocean influenced air mass that could affect the air chemistry of the Halifax urban air shed. Unfortunately in order to produce an accurate source budget for the seasonal pollutants a full chemical speciation study would have to be undertaken, which is outside the scope of the current project.

4.5 NAPS SITE BEHAVIOUR

When exploring the variation of AQHI within sampling campaigns there is a striking difference between the AQHI for the NAPS site and the sample site AQHI's as well as the component pollutants. In the winter NO_2 ($p \leq 0.001$) and $PM_{2.5}$ ($p=0.028$) are both significantly higher for the NAPS station, than observed for the site values while O_3 is not ($P=0.414$). During the summer sampling campaign all three of the pollutants significantly differ ($P<0.001$) from one another suggesting there is a fundamental difference in the air quality being sampled at the NAPS site compared to the sampling sites; even if the overall levels are varying in a similar manner to that of the sample sites as seen above. The variation in pollutant levels could be the result of several factors, however the most obvious is the different built environment in which the NAPS site is located.

The NAPS site is located in downtown Halifax in the most built up region of the city and is located on the roof of a provincial government office building above some of the most continuously busy streets in the city (elevation above street level is approximately 20 m). This different sampling environment results in higher anthropogenic pollution including NO_2 and $PM_{2.5}$ and thus higher levels of AQHI. In contrast to this the reported AQHI is not as different from the sampled AQHI values as a result of the balancing effect of the second NAPS site located at Lake Major in Dartmouth.

Unfortunately, the NAPS site data for both NO_2 and $PM_{2.5}$ for the sample campaigns was not available for review, however it is clear from the temporal variation of the reported AQHI that it has a different air pollution profile than that observed in the city. The literature supports rural or peri-rural sites having different pollutant profiles compared to urban sites as a result of various anthropogenic indicators but also due to absorption and production of pollutants by vegetation. This can be seen between for the AQHI pollutants between Halifax and the Annapolis Valley(82) as well as in other locations around the world .

4.6 SPATIAL ANALYSIS

From a spatial perspective, similar spatial distributions for $PM_{2.5}$ are seen for both sampling campaigns. There are elevated levels in eastern Dartmouth and hot spots in both Sackville and Bedford in the winter (Figure. 29). While in the summer there are elevated levels in western Halifax with similar hotspots in Sackville and Bedford. NO_2 has a similar distribution between seasons with peaks in the most heavily populated areas of the region. It is clear the interpolation is dominated by local point sources like domestic combustion sources for space or water heating, barbeques or lawnmowers or vehicle traffic which is a clear example of how local influences can affect air quality (83). During the winter NO_2 levels are twice that of the summer and are concentrated around more heavily populated areas which is indicative of NO_2 production from residential heating and is reflected in other studies (Figure. 30) (48,84).

O_3 also demonstrates a similar pattern between summer and winter as NO_2 but O_3 has the inverse spatial distribution pattern and tends to be higher away from populated areas, this pattern is particularly pronounced in the winter as well O_3 levels are higher in the winter. It is important to note the inverse relationship between NO_2 and O_3 which is evidence of titration of O_3 by NO as described by equations 2a and 2b (Figures. 30 and 31) (20,85).

The interpolated AQHI values using the site-specific AQHI values demonstrates an inverse pattern between winter and summer with high AQHI values in more heavily populated areas in the winter and lower in the summer (Figure. 32). A weakness of using an interpolation method such as Natural Neighbours is that it is dominated by local point sources because it depends on the values as sampled rather than calculating pixel values as a more robust method such as a LUR. However, even with these considerations an interpolated surface provides valuable information about the distribution of pollutants around the region and helps in picturing the data.

4.7 Rounded AQHI comparison

The final step in data analysis which was conducted for this project was rounding the calculated AQHI values for all sites to explore the variation in terms of how it would be presented to the public. For this test the data was simply rounded to the closest whole number. The data was then cross tabulated by SAS first as all values, then by sample site and finally by sample day for both sample site vs NAPS and sample site vs reported AQHI. Modifying the data in this manner allows an exploration of reporting errors as well as the impact that it would have on health messages given to the public and how that would change; which will be discussed in the following section.

In the winter the most common reported AQHI is three with 50% of all values, followed by two with 46% of the values – the remainder is four. However, the most common sample site AQHI values is two with 81% of the values followed by three with 15% and one and four both at 2.5%. The most common misclassification was a site value of two being reported as a three (50% of data points). Of particular interest in the winter period is four sample locations with an AQHI of four however the daily AQHI was only reported as a two, showing the clear influence of local conditions.

In the summer, the most common reported AQHI value is two with 62% of the data followed by one with 34% of the data. The most common sample site AQHI however is one with 83% of the data. In the summer the most common misclassification is a one being reported as a two with 57% of the sample site AQHI one values being misreported. For both the summer and the winter campaigns there is a clear variation for a large portion of the data with over half of the data being reported differently from local conditions.

In order to better understand the patterns behind the variability seen in the rounded values cross tabulation by site was undertaken. However there was surprisingly little consistency between which sample sites matched more closely with the reported AQHI from a spatial perspective as shown in Figures 35 and 36. So a third cross tabulation was undertaken using sample day in order to explore the temporal variation. Through this analysis temporal trends can be recognized as areas of high or low agreement which tend to occur in blocks of time, related to the level of the AQHI. In Figures 33 and 34 (winter and summer respectively) the relationship between the reported AQHI, the red line and the percent of samples taken on a given day which are different from the reported AQHI value in blue. The trend seems to be that when the AQHI is higher there is more disagreement between the sample sites and reported AQHI. There could be various drives for this including both traffic patterns and meteorological conditions however greater sampling depth and modeling would need to be undertaken in order to better understand these drivers.

4.8 HEALTH AND POLICY IMPLICATION

From the prospective of a policy maker there are a few key findings which are important for making determinations around the accuracy of the AQHI in Halifax. First, from a physical perspective, it is clear that the winter has worse air quality than that of the summer. In terms of population exposure, this generally a beneficial feature with respect to the AQHI, as the majority of the population are outside and more active in the summer than compared to the winter within the region. It is important to note that there is significant infiltration of outdoor pollutants into the indoor environment. Outdoor air infiltrates into the indoor environment at an approximate rate of full volume exchange in approximately 2 hours(86,87) and while there will be some pollutant loss during this exchange the indoor environment offers its own suite of pollutants and sources which can be harmful to human health.

Second, while the reported AQHI is giving a statistically different value than the locally calculated AQHI values it is over reporting these values. This is good from a policy prospective, as it is better to err on the side of caution rather than under predict and tell the public that the air quality is better than it is. Unfortunately however, the AQHI is providing the wrong value 53% of the time in the winter and 55% in the summer when compared to the local sites. This is a concern because it underlines the challenge of assigning central site pollutant values to an area at large and the affect that local influences can have. However one of the strengths of the AQHI is that even if the values are being miss reported because it is a 1 to 10+ scale, the public can still self calibrate for their local region and take appropriate steps to protect themselves.

This demonstrates that great care needs to be taken when placing these sites as the readings of the central sites is also a result of the local area. There does not seem to be a strong spatial trend when exploring the differences from the reported AQHI and the site AQHI values. But there is a temporal tend in the reported error, this suggests that indicates outside influences such as weather could be driving the variation and might be predictable with further sampling and modelling.

When the actual differences are examined it can be seen that the most common mistakes are reporting a two for a one in the summer and three for a two in the winter. When the actual AQHI health messages for those AQHI level are assessed (AQHI levels and health messaging can be found in Appendix. C) there is no change in the health messaging between these two values. In the next decade and beyond as the environmental footprint, density and population of Halifax continues to increase this small variation could become a greater concern. Research has demonstrated that larger cities have increased levels of air pollution(26,88,89) and with an increase of one AQHI point across the board there would be a change in the health messaging that would be provided to the public. This also raises concerns for cities larger then Halifax. It is possible that the reported AQHI is not actually representing the levels of air pollution that are occurring where people are living and working as a result of structural differences in where air pollution is being sampled.

4.9 STRENGTHS AND LIMITATIONS

This study, as with all studies comes with both strengths and limitations. The ancestral study which supplied the data was a broad based study using stratified random sampling in both the summer and winter seasons, incorporating a large number of participants and a long temporal span in the sampling campaigns. Providing a large, temporally, spatially and strong data set with minimal missing data. The data set is particularly strong for seasonal comparisons, and comparisons between the sample sites, the NAPS site values and the reported AQHI.

There are weaknesses in the data set however, particularly in the within season analysis. Each sample site had at most seven sample points to be compared which is not a strong sample and identifies a weakness in the statistical analysis. Secondly, comparison between the co-located samplers with the NAPS site instruments was not possible for either NO_2 or $PM_{2.5}$, which undermines the accuracy of the field instruments. While this can be partially countered by relying on other studies which used the same type of samplers co-located with other NAPS sites it is not ideal. Also NAPS site data for Lake Major was not available, making it difficult to completely understand the impact which it has on the reported AQHI and to compare that data to the 50 sample site data. Spatially, the distribution of the data points was not idea for spatial interpolation. Data points were clustered in areas where single family homes are located and avoid areas of either industrial development, regions with apartments or green space. This is unavoidable as the original study was structured for examining air pollution in residential homes.

Despite the weaknesses in sample size and comparative NAPS site data the advantages of this study greatly outweigh the weaknesses. There is very little published research involving the AQHI and as it is currently being used as the indicator of air quality it is important to understand how the AQHI behaves over both space and time and how accurate the central site reporting is at reflecting ground level pollution levels.

CHAPTER 5.0 CONCLUSIONS

The AQHI, currently in use by the Canadian government, is a multi-pollutant public health information tool that is based upon extensive Canadian epidemiological evidence(32). As the AQHI is a relatively new metric, there is little published information about the accuracy to ground level conditions or the spatial and temporal behaviour of the metric. The HIAQS is a two season data set with 50 sample sites distributed around the urban and sub-urban areas of Halifax and provides an opportunity to expand the body of knowledge pertaining to the AQHI's accuracy and spatial and temporal behaviour in two seasons.

The goals of this work were several fold; first to develop daily AQHI values for the 50 residential sample sites, the Halifax NAPS site and the reported AQHI to assess the accuracy of the reported AQHI for local ground level conditions. As well as to provide more information to the scientific community on the spatial and temporal behaviour of the AQHI. To achieve these goals, statistical analysis was undertaken to explore both seasonal and within season variation of the AQHI and pollutants. Explore the spatial and temporal trends of the AQHI and to understand the variation of the reported AQHI compared to the 50 seasonal sample sites using the AQHI as it would be reported to the public. Spatial interpolation was conducted to gain a better visual understanding of the spatial and seasonal distribution of the AQHI component pollutants and the AQHI itself.

Air quality in the Halifax region is very good, AQHI values were predominantly in the 1 to 3 range on the AQHI scale which corresponds to very good air quality and no behaviour or activity restrictions are suggested by the AQHI health messages for the majority of the population. However, the reported AQHI was found to be significantly different from the sample site AQHI values for both seasons ($P \leq 0.001$ for both seasons). In both seasons, the reported AQHI was over reporting the AQHI calculated for the sampling sites ($P=0.05$) but was statistically the same as the Halifax NAPS site. While this seems to suggest that the AQHI could be calculated using only the central NAPS site other analysis demonstrates that the Halifax central NAPS site has higher values than the reported AQHI and has significantly higher pollutants levels than the sample sites and to remove the counter balance of the Lake Major site may not be useful. Further analysis using the two NAPS sites would need to be conducted to make a full assessment.

The AQHI index values were significantly different ($P \leq 0.001$) between the winter and summer sampling campaigns, this variation was driven by elevated levels of O_3 and NO_2 in the winter when compared to the summer. While this variation was low (one AQHI index point) it does identify a base level change in the quality of air in the region. The elevated levels of O_3 in the winter are the result of seasonal variation in atmospheric chemistry and meteorological conditions, while the changes in NO_2 levels are the result of seasonal changes in anthropogenic behaviour, e.g. increased space heating and differing driving behaviour in the winter and seasonal changes in the amount of vegetation available for scavenging (20,90).

Within season variation was more complex. This analysis was conducted using three data bins, the sample sites, NAPS site and reported AQHI. Both AQHI levels and temporal variation for all three data bins were reported. During the winter there was low variation in AQHI levels between the sample sites and stronger agreement with the reported AQHI values when compared to the summer sampling campaign. In the summer, the AQHI levels were lower but there was a higher level of site to site variation and less agreement with the reported AQHI.

The co-linear variation within the sample sites and between the sample sites and reported AQHI was similar for both seasons; but lower in both cases in the summer. However in the summer there was much higher percentage of co-variation between the sites and the NAPS site (26% in the winter and 44% in the summer). This suggests that during the winter the air quality in the downtown core of Halifax, where the NAPS station is located, is significantly different than the summer, most likely as a result of NO_X and $PM_{2.5}$ related space heating emissions in the winter coupled with meteorological influences, e.g. temperature inversions. Using the spatial interpolation technique Natural Neighbours , it was observed that the spatial variation in the region was low. The utility of the Natural Neighbours was demonstrated as it provided a spatial example of the titration of O_3 by NO which is described in previous work (20). The analysis also identified strong influences of local conditions on air quality, particularly in the winter and provided a visual of the variation of air quality around the region.

Because the AQHI is reported to the public on a 1 to 10+ whole number index scale it was important to assess the variation of the AQHI values in this manner to better understand the AQHI variation as it would be reported to the public. This analysis identified that more than 50% of the daily AQHI index values in both seasons were reported different than the local sites sampled as the same time., The reported AQHI most commonly over predicted by one AQHI index point. This analysis also identified no strong spatial pattern of AQHI disagreement between the repoted AQHI and the sample sites; i.e. that the location of the sample site did not seem to have an influence on the amount of disagreement between the reported AQHI and the sample site. Instead a temporal trend of disagreement was identified. During periods when the AQHI was higher, there was greater disagreement between the reported AQHI and the sample sites.

There are both positive and negative health policy implications to this research. First the reported AQHI is different from the AQHI sampled at local sites more than 50% of the time, second, the reported AQHI was over predicting the levels of air pollution and the most common miss-reporting errors were one AQHI point in both seasons. In addition, more miss-reported errors were found when the AQHI was reported as higher value which raises some concern regarding the behaviour of the AQHI both in larger cities and over the next decade as Halifax increases in size. The miss-reporting of AQHI values also raises some concern for epidemiological work, e.g. if the AQHI is used as an exposure metric it could over estimate exposure to air pollution. However, the AQHI is a useful scientific metric which has several advantages, first it is a multi pollutant measure based on sound epidemiological evidence linking a mixture of three major air pollutant metrics to deathrates in Canadian cities and second that it has been distilled into a form that is readily understood by the public making the communication of results to non experts easier.

This project has been successful in providing more information to the scientific community on the spatial and temporal variation of the AQHI in the Halifax region. It has been able to identify both seasonal and temporal variation, reinforced the understanding of pollutant behaviour and has begun to provide information on the behaviour of the AQHI on small urban scales and provide valuable information for both researchers and policy makers on the AQHI from a public health context.

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APPENDIX A: WINTER SAMPLING CAMPAIGN

WEEK TWO, WINTER SAMPLING CAMPAIGN (JANUARY 19 TO JANUARY 25, 2009)

The median AQHI value for week two is 2.2 while the maximum and minimum are 3.7 and 1.7 respectively. The reported AQHI value is significantly higher than the site AQHI values, and does not reflect either an unusual spike on January 21st or the slight drop on January 24th both these events are identified by the NAPS site and as such these events are city wide. Deviation from the reported values are shown in the normalized plot (Figure. 2) and data distribution is in the box plot (Figure. 3). Dominant wind patterns for this sampling week are from the south west with a significant south east component.

Statistics were calculated using Kruskal-Wallis ANOVA and while a significant difference was found the pairwise multiple comparison (Tukey's Test) was not able to identify which groups were different. Correlation coefficients were calculated by the Spearman Rank Order method:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
HFAX-0077		0	1.917	1.791	2.352
HFAX-0087		0	1.989	1.741	2.222
HFAX-0097		0	2.249	2.092	2.678
HFAX-0107		0	2.057	1.831	2.302
HFAX-0117		0	2.114	1.811	2.348
HFAX-0127		0	1.992	1.912	2.275
NAPS	7	0	2.589	2.509	3.053
reported	7	0	2.594	2.245	2.729

H = 17.180 with 7 degrees of freedom. (P = 0.016)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.016)

All Pairwise Multiple Comparison Procedures (Tukey's Test):

Comparison	**Diff of Ranks**	**q**	**P<0.05**
NAPS vs HFAX-008	169.000	3.916	No
NAPS vs HFAX-007	160.000	3.708	Do Not Test
NAPS vs HFAX-010	155.000	3.592	Do Not Test
NAPS vs HFAX-011	151.000	3.499	Do Not Test
NAPS vs HFAX-012	142.000	3.291	Do Not Test
NAPS vs HFAX-009	80.000	1.854	Do Not Test
NAPS vs reported	19.000	0.440	Do Not Test
reported vs HFAX-008	150.000	3.476	Do Not Test
reported vs HFAX-007	141.000	3.268	Do Not Test
reported vs HFAX-010	136.000	3.152	Do Not Test
reported vs HFAX-011	132.000	3.059	Do Not Test
reported vs HFAX-012	123.000	2.850	Do Not Test
reported vs HFAX-009	61.000	1.414	Do Not Test
HFAX-009 vs HFAX-008	89.000	2.063	Do Not Test
HFAX-009 vs HFAX-007	80.000	1.854	Do Not Test
HFAX-009 vs HFAX-010	75.000	1.738	Do Not Test
HFAX-009 vs HFAX-011	71.000	1.645	Do Not Test
HFAX-009 vs HFAX-012	62.000	1.437	Do Not Test
HFAX-012 vs HFAX-008	27.000	0.626	Do Not Test
HFAX-012 vs HFAX-007	18.000	0.417	Do Not Test
HFAX-012 vs HFAX-010	13.000	0.301	Do Not Test
HFAX-012 vs HFAX-011	9.000	0.209	Do Not Test
HFAX-011 vs HFAX-008	18.000	0.417	Do Not Test

HFAX-011 vs HFAX-007	9.000	0.209	Do Not Test
HFAX-011 vs HFAX-010	4.000	0.0927	Do Not Test
HFAX-010 vs HFAX-008	14.000	0.324	Do Not Test
HFAX-010 vs HFAX-007	5.000	0.116	Do Not Test
HFAX-007 vs HFAX-008	9.000	0.209	Do Not Test

Spearman Rank Order Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-008	**HFAX-009**	**HFAX-010**	**HFAX-011**	**HFAX-012**	**NAPS**	**eported**
HFAX-007	0.750	0.857	0.893	0.929	0.964	0.536	0.143
	0.038	0.006	0.000	0.000	0.000	0.181	0.720
	7	7	7	7	7	7	7
HFAX-008		0.679	0.429	0.821	0.857	0.357	-0.036
		0.074	0.297	0.015	0.006	0.388	0.905
		7	7	7	7	7	7
HFAX-009			0.750	0.786	0.893	0.679	0.107
			0.034	0.0251	0.000	0.074	0.781
			7	7	7	7	7
HFAX-010				0.714	0.786	0.643	0.214
				0.055	0.025	0.096	0.602
				7	7	7	7
HFAX-011					0.964	0.321	0.036
					0.000	0.438	0.905
					7	7	7
HFAX-012						0.500	0.107
						0.217	0.781
						7	7
NAPS							-0.286
							0.491
							7

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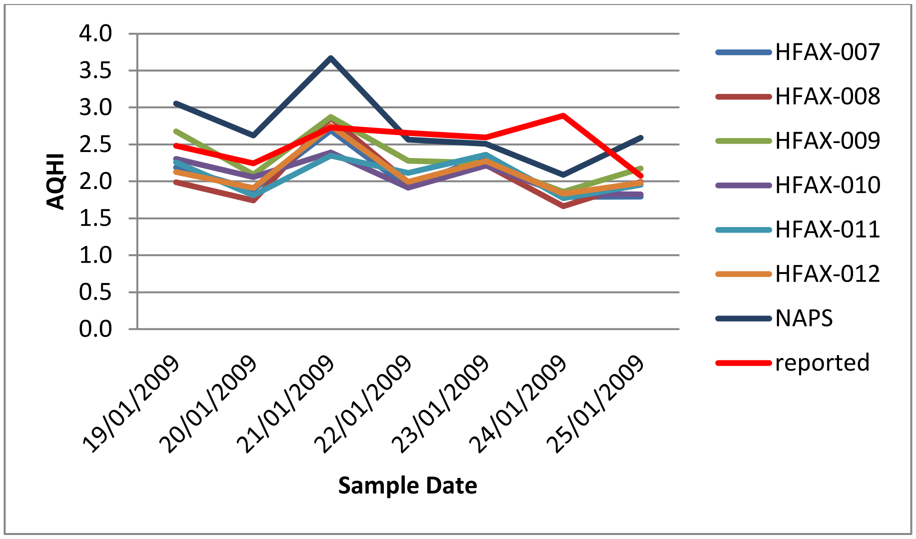

Figure 37. Time series for week two of the winter sampling campaign

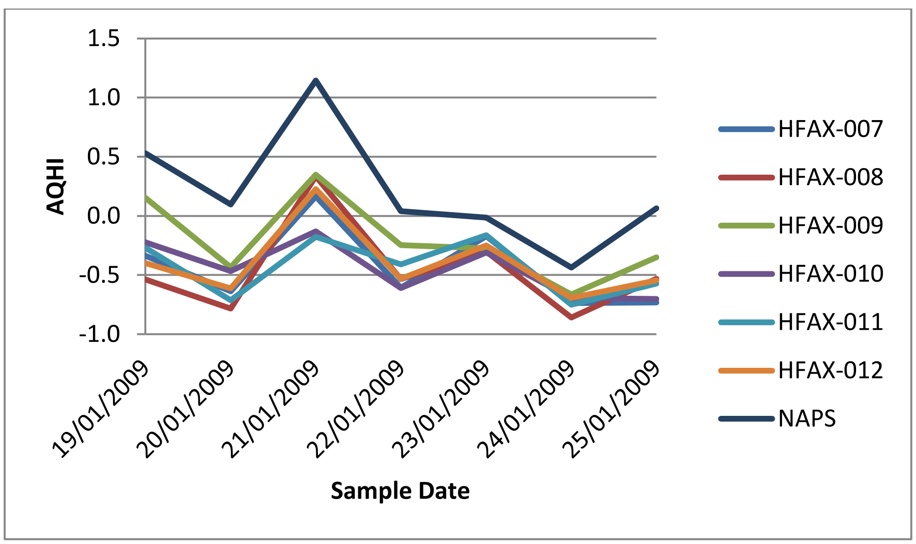

Figure 38. Time series of AQHI values from the sample sites and NAPS station normalized to the reported AQHI values for week two of the winter sampling campaign

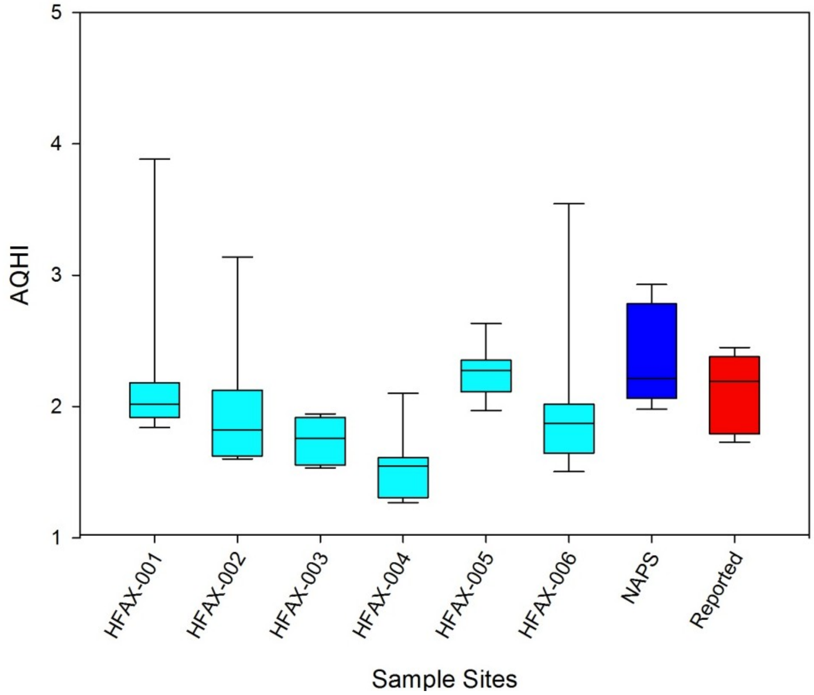

Figure 39. Box plot showing the AQHI data from the second week of sampling from the winter campaign.

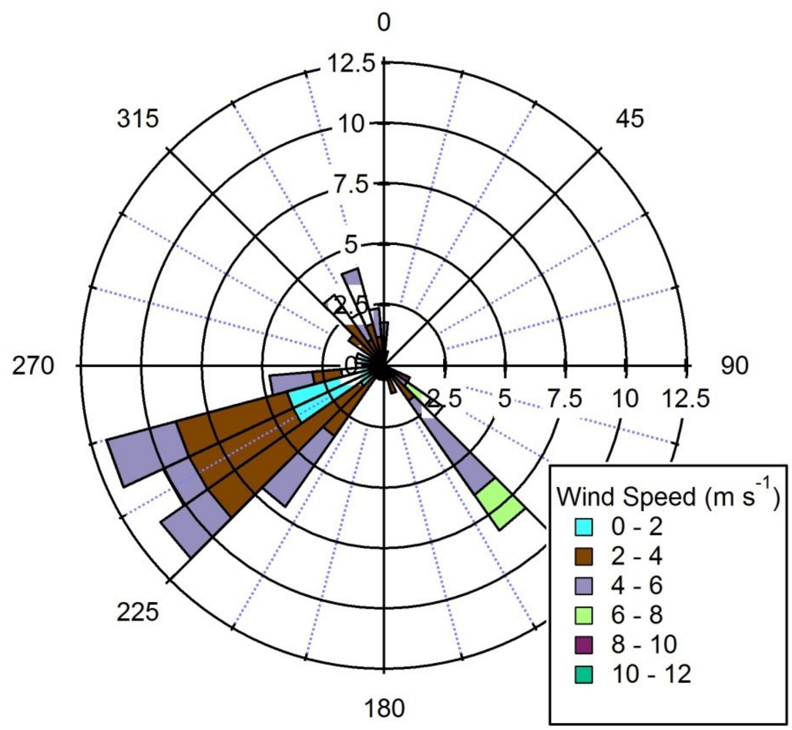

Figure 40. Wind direction and speed from week two of the winter sampling campaign.

Week three, winter sampling campaign (January 29 to February 04, 2009)

In week three one day of data was lost leaving six sampled days, the median maximum and minimum AQHI values were 2.3, 3.3 and 1.2 respectively. The weekly time series (Figure. 5) demonstrates a more mixed pattern for this week then previous weeks, but with the reported AQHI generally higher than that of the sampled sites and following an inverse trend. The dominant wind trends are again from the south west, however there is a second component from the south east and some smaller tertiary components Figure. 8).

The data for week three is normally distributed allowing for the more powerful ANOVA test and Holm-Sidak multiple Comparison Procedure to be conducted and to identify that site HFAX-015 is significantly different from the reported AQHI values ($p<0.05$). The shape of the data allows for the use of Pearson Product Moments Correlation to calculate correlation coefficients:

Normality Test (Shapiro-Wilk) Passed (P = 0.935)

Equal Variance Test: Passed (P = 0.905)

Group Name	N	Missing	Mean	Std Dev	SEM
HFAX-014	6	0	2.260	0.249	0.102
HFAX-015	6	0	2.004	0.332	0.136
HFAX-016	6	0	2.175	0.428	0.175
HFAX-017	6	0	2.040	0.402	0.164
HFAX-018	6	0	2.234	0.336	0.137
NAPS	6	0	2.750	0.342	0.140
reported	6	0	2.653	0.197	0.0803

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P = 0.002$).

Power of performed test with alpha = 0.050: 0.908

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):

Overall significance level = 0.05

Comparisons for factor:

Comparison	**Diff of Means**	**t**	**P**	**P<0.050**
NAPS vs. HFAX-015	0.746	3.858	0.010	Yes
NAPS vs. HFAX-017	0.709	3.669	0.016	Yes
reported vs. HFAX-015	0.649	3.357	0.036	Yes
reported vs. HFAX-017	0.613	3.169	0.056	No
NAPS vs. HFAX-016	0.575	2.974	0.086	No
NAPS vs. HFAX-018	0.515	2.666	0.170	No
NAPS vs. HFAX-014	0.490	2.534	0.214	No
reported vs. HFAX-016	0.478	2.473	0.229	No
reported vs. HFAX-018	0.419	2.165	0.390	No
reported vs. HFAX-014	0.393	2.034	0.457	No
HFAX-014 vs. HFAX-015	0.256	1.324	0.907	No
HFAX-018 vs. HFAX-015	0.231	1.192	0.937	No
HFAX-014 vs. HFAX-017	0.219	1.135	0.937	No
HFAX-018 vs. HFAX-017	0.194	1.004	0.956	No
HFAX-016 vs. HFAX-015	0.171	0.884	0.966	No
HFAX-016 vs. HFAX-017	0.135	0.696	0.983	No
NAPS vs. reported	0.0968	0.500	0.992	No
HFAX-014 vs. HFAX-016	0.0850	0.439	0.987	No
HFAX-018 vs. HFAX-016	0.0596	0.308	0.986	No
HFAX-017 vs. HFAX-015	0.0364	0.188	0.978	No
HFAX-014 vs. HFAX-018	0.0254	0.131	0.896	No

Pearson Product Moment Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-015	HFAX-016	HFAX-017	HFAX-018	NAPS	reported
HFAX-014	0.382	0.707	0.921	0.836	0.796	-0.973
	0.454	0.116	0.01	0.038	0.058	0.001
	6	6	6	6	6	6
HFAX-015		0.835	0.507	0.083	0.840	-0.261
		0.0387	0.305	0.875	0.036	0.617
		6	6	6	6	6
HFAX-016			0.695	0.563	0.952	-0.585
			0.125	0.245	0.003	0.222
			6	6	6	6
HFAX-017				0.671	0.852	-0.873
				0.144	0.031	0.023
				6	6	6
HFAX-018					0.530	-0.869
					0.280	0.025
					6	6
NAPS						-0.678
						0.139
						6

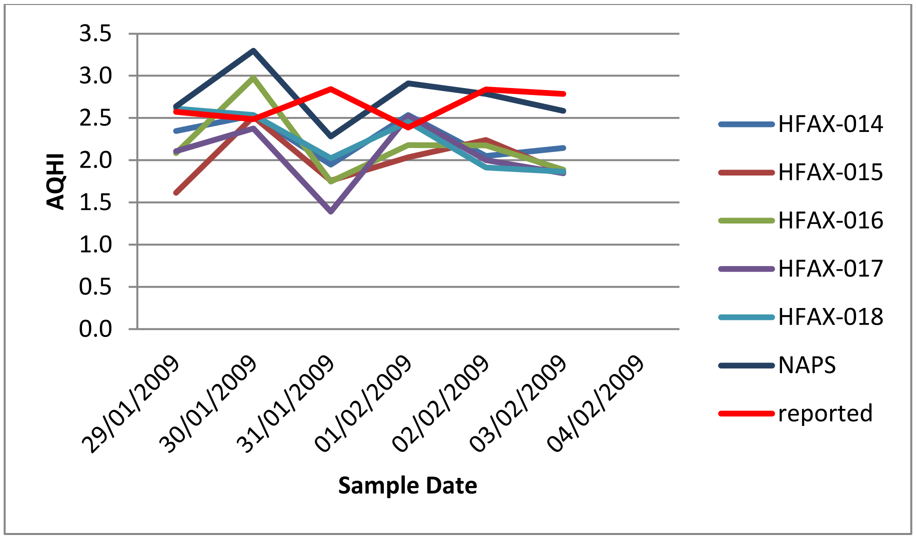

Figure 41. Time series of week three of the winter sampling campaign.

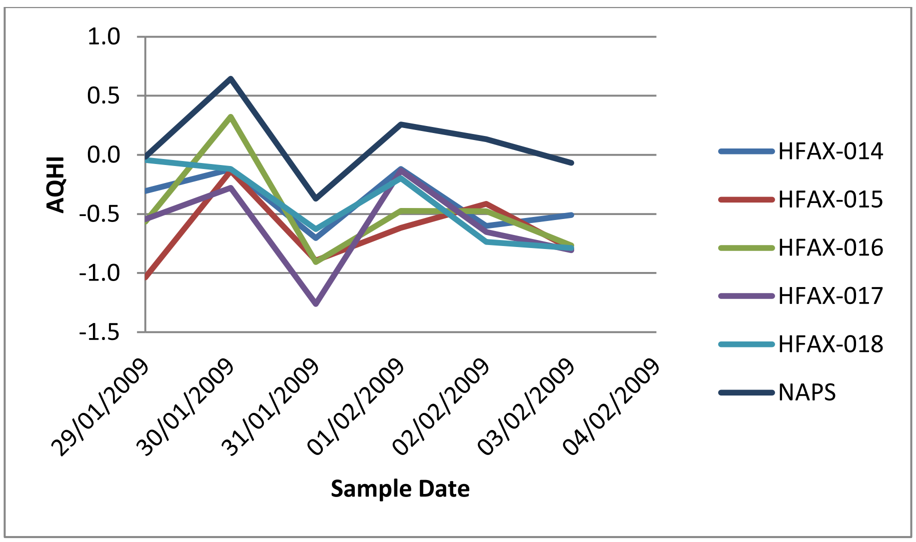

Figure 42. Deviations from the normalized reported AQHI values for site and NAPS AQHI values.

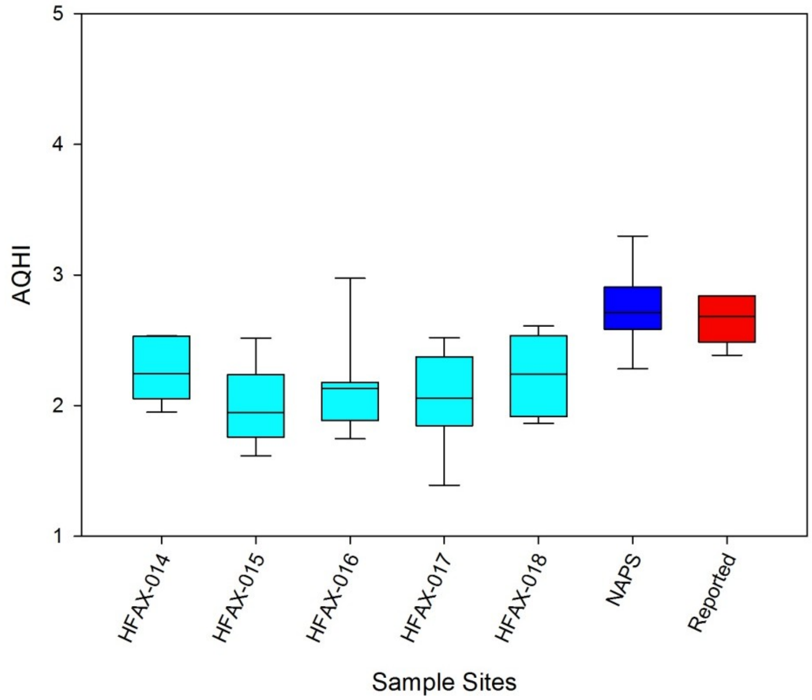

Figure 43. Box plot of the AQHI values for week three of the winter sampling campaign.

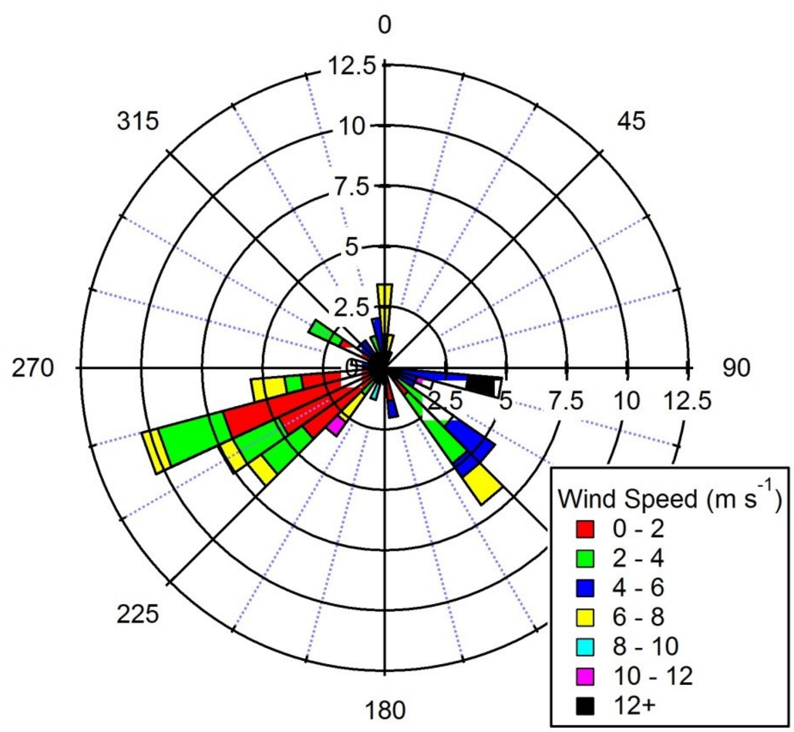

Figure 44. Wind rose of week three of the winter sampling campaign.

WEEK FOUR, WINTER SAMPLING CAMPAIGN (FEBRUARY 09 TO FEBRUARY 15, 2009)

Week four exhibits a median AQHI value of 2.1 and a maximum and minimum of 3.2 and 1.5 respectively. The time series plot shows a mixed pattern of AQHI levels with no distinct trends (Figure. 9). Deviations from the reported values show a similar lack of a clear pattern across the sample sites (Figure. 10). The dominant wind pattern is from the west with a small secondary component from the South East (Figure. 12).

The data from sampling week four passes both normality and equal variance tests allowing one way ANOVA to be uses as well as the Holm-Sidak method for multiple comparisons. While there was a significant difference between the groups it was between the NAPS station and two of the sampling sites. The Person Product Moment Correlation method was used to calculate correlation coefficients:

Normality Test (Shapiro-Wilk) Passed (P = 0.051)

Equal Variance Test: Passed (P = 0.713)

Group Name	**N**	**Missing**	**Mean**	**Std Dev**	**SEM**
HFAX-019	7	0	1.784	0.271	0.103
HFAX-021	7	0	2.143	0.311	0.118
HFAX-022	7	0	2.030	0.278	0.105
HFAX-023	7	0	1.901	0.341	0.129
HFAX-024	7	0	2.082	0.466	0.176
NAPS	7	0	2.596	0.460	0.174
reported	7	0	2.356	0.301	0.114

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.002).

Power of performed test with alpha = 0.050: 0.886

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):
Overall significance level = 0.05

Comparisons for factor:

Comparison	**Diff of Means**	**t**	**P**	**P<0.050**
NAPS vs. HFAX-019	0.812	4.276	0.002	Yes
NAPS vs. HFAX-023	0.695	3.659	0.014	Yes
reported vs. HFAX-019	0.573	3.016	0.079	No
NAPS vs. HFAX-022	0.565	2.978	0.083	No
NAPS vs. HFAX-024	0.514	2.705	0.154	No
reported vs. HFAX-023	0.455	2.399	0.287	No
NAPS vs. HFAX-021	0.452	2.384	0.281	No
HFAX-021 vs. HFAX-019	0.359	1.892	0.612	No
reported vs. HFAX-022	0.326	1.719	0.719	No
HFAX-024 vs. HFAX-019	0.298	1.571	0.795	No
reported vs. HFAX-024	0.274	1.446	0.845	No
HFAX-022 vs. HFAX-019	0.246	1.298	0.895	No
HFAX-021 vs. HFAX-023	0.242	1.275	0.879	No
NAPS vs. reported	0.239	1.260	0.855	No
reported vs. HFAX-021	0.213	1.124	0.887	No
HFAX-024 vs. HFAX-023	0.181	0.954	0.922	No
HFAX-022 vs. HFAX-023	0.129	0.681	0.969	No
HFAX-023 vs. HFAX-019	0.117	0.617	0.955	No
HFAX-021 vs. HFAX-022	0.113	0.595	0.912	No
HFAX-021 vs. HFAX-024	0.0610	0.321	0.937	No
HFAX-024 vs. HFAX-022	0.0518	0.273	0.786	No

Pearson Product Moment Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-021	HFAX-022	HFAX-023	HFAX-024	NAPS	reported
HFAX-019	0.835	-0.235	-0.118	0.754	0.912	0.670
	0.019	0.611	0.802	0.050	0.004	0.099
	7	7	7	7	7	7
HFAX-021		0.0860	0.344	0.531	0.790	0.317
		0.855	0.451	0.220	0.034	0.489
		7	7	7	7	7
HFAX-022			0.556	-0.614	0.010	-0.103
			0.195	0.142	0.983	0.827
			7	7	7	7
HFAX-023				-0.252	0.033	-0.342
				0.585	0.943	0.453
				7	7	7
HFAX-024					0.689	0.221
					0.087	0.634
					7	7
NAPS						0.576
						0.176
						7

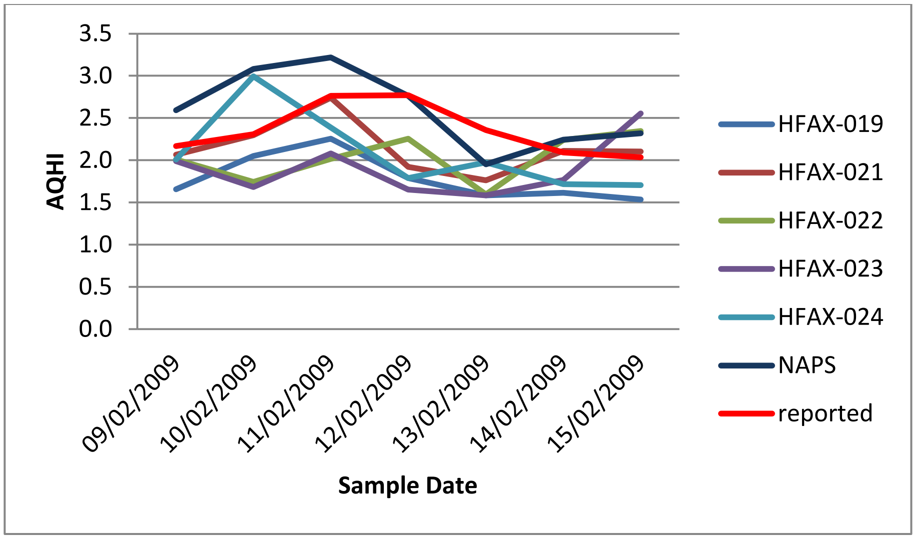

Figure 45. Time series of AQHI values from week four of the winter sampling campaign.

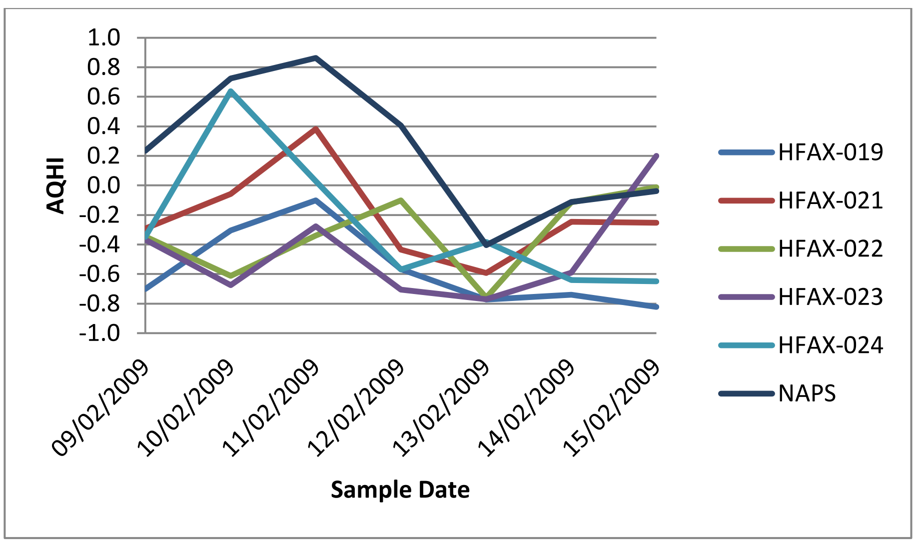

Figure 46. Deviation from the reported AQHI values with no clear pattern.

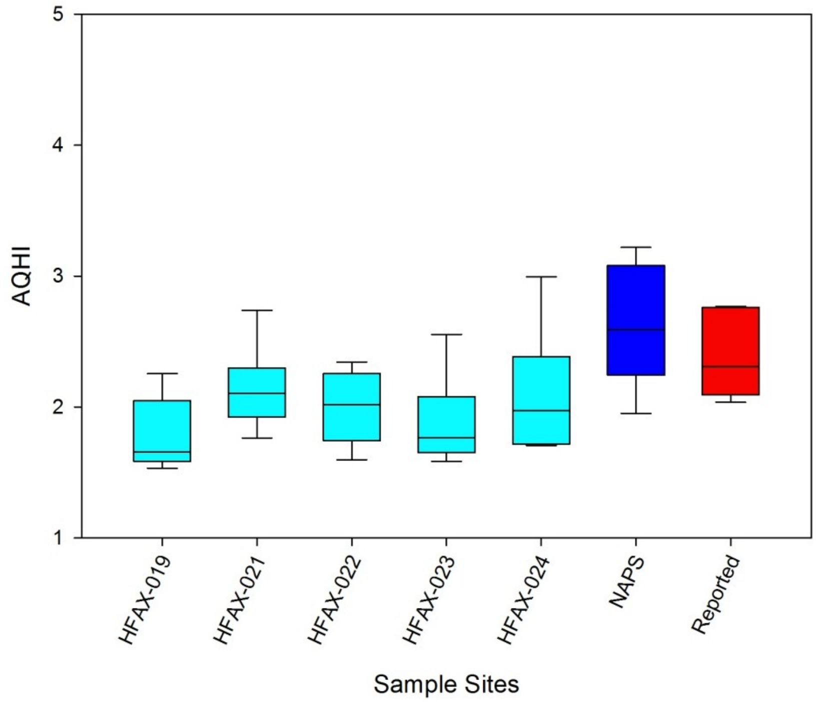

Figure 47. Box plot showing variation of AQHI values across the week four sampling sites.

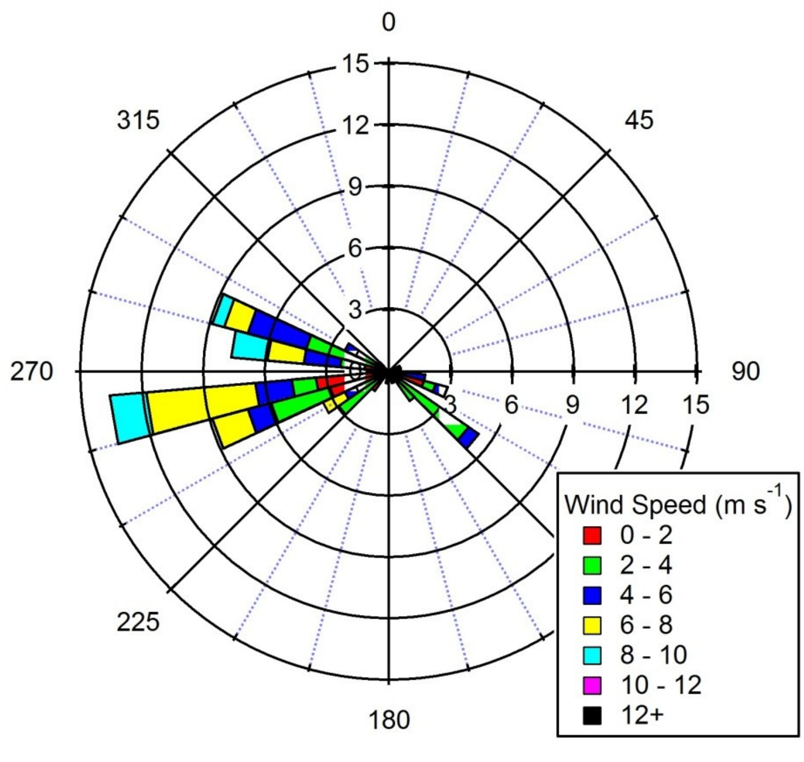

Figure 48. Wind rose plot showing the strong western wind trend for the sampling week.

WEEK FIVE, WINTER SAMPLING CAMPAIGN (FEBRUARY 20 TO FEBRUARY 26, 2009)

The AQHI data from week five ranges from a minimum of 1.6 to a maximum of 4 with a median of 2.1. There is one day of data missing however the available data shows a city wide trend of increasing AQHI values that is not reflected in reported AQHI (Figure. 13). Deviation from the reported AQHI increases later in the sampling week as pollution levels rise (Figure. 14). The increasing pollution levels are reflected in the high variability of the data as shown in Figure. 15). Wind data is not available for this sampling week.

The data failed the normality test and as such Kruskal-Wallis ANOVA was used, however there was not a significant difference between the groups, Spearman Rank Order Correlation calculations were used to produce correlation coefficients:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
HFAX-0256		0	1.867	1.686	2.398
HFAX-0266		0	2.124	1.959	2.711
HFAX-0276		0	2.129	1.844	2.661
HFAX-0286		0	2.003	1.761	2.397
HFAX-0296		0	1.782	1.655	2.253
HFAX-0306		0	1.862	1.744	2.146
NAPS	6	0	2.271	1.981	3.143
reported	6	0	2.317	2.222	2.555

$H = 11.122$ with 7 degrees of freedom. ($P = 0.133$)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.133)

Spearman Rank Order Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-026	**HFAX-027**	**HFAX-028**	**HFAX-029**	**HFAX-030**	**NAPS**	**reported**
HFAX-025	0.829	0.486	0.371	0.886	0.657	0.886	0.028
	0.058	0.356	0.497	0.033	0.175	0.033	1.000
	6	6	6	6	6	6	6
HFAX-026		0.657	0.714	0.829	0.943	0.829	-0.486
		0.175	0.136	0.058	0.017	0.058	0.356
		6	6	6	6	6	6
HFAX-027			0.886	0.714	0.829	0.714	-0.314
			0.033	0.136	0.058	0.136	0.564
			6	6	6	6	6
HFAX-028				0.657	0.886	0.657	-0.543
				0.175	0.033	0.175	0.297
				6	6	6	6
HFAX-029					0.771	1.000	-0.143
					0.103	0.003	0.803
					6	6	6
HFAX-030						0.771	-0.600
						0.103	0.242
						6	6
NAPS							-0.143
							0.803
							6

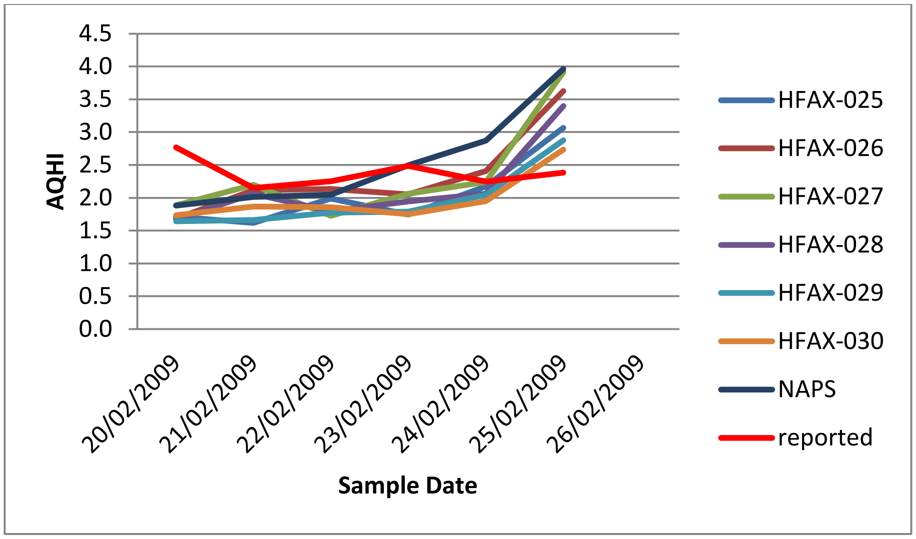

Figure 49. Time series of AQHI data from week five of the winter sampling campaign.

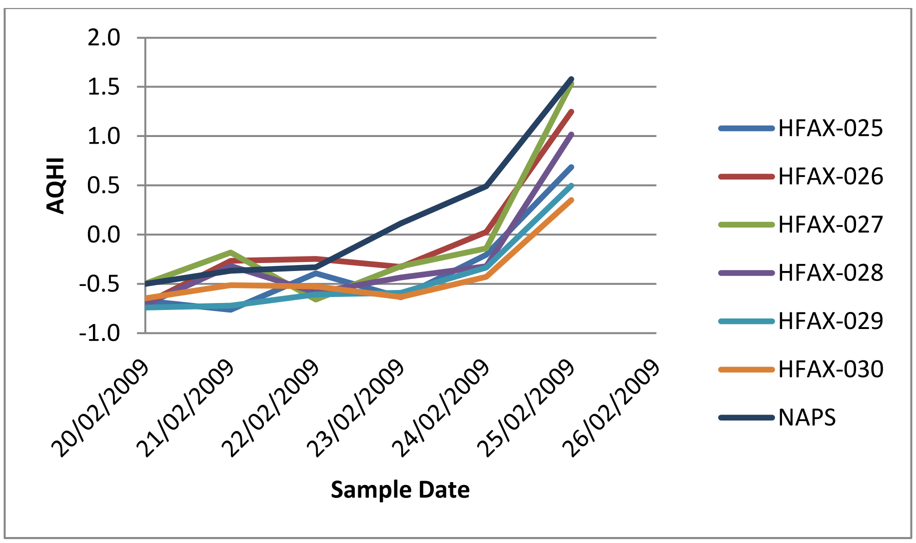

Figure 50. Time series of deviation from the reported AQHI for week five of the winter sampling campaign

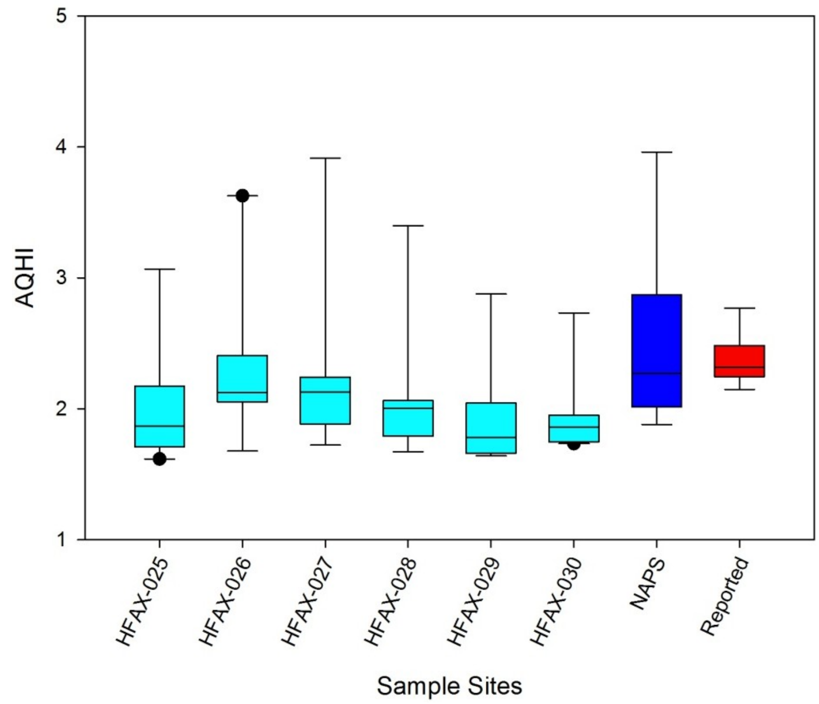

Figure 51. Box plot of the data from week five of the winter sampling campaign.

WEEK SIX, WINTER SAMPLING CAMPAIGN (MARCH 2 TO MARCH 8, 2009)

AQHI values from sampling week six demonstrate two city wide events of increased AQHI, there are not reflected in the reported AQHI (Figure. 16). The deviation from the reported AQHI is higher during the first event and is variable between sites (Figure. 17). Median AQHI is 2.19 while the maximum and minimum are 3.26 and 1.46 respectively. No wind data was available from this sampling week.

Statistics were calculated using Kruskal-Wallis ANOVA which did not find a difference between the samples while the Spearman Rank Order Correlation method was used:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Kruskal-Wallis One Way Analysis of Variance on Ranks Wednesday, May 11, 2011, 9:12:38 PM

Group	N	Missing	Median	25%	75%
HFAX-0317		0	1.978	1.932	2.502
HFAX-0327		0	1.869	1.721	2.317
HFAX-0337		0	2.068	1.819	2.973
HFAX-0347		0	2.032	1.788	2.591
HFAX-0367		0	2.035	1.985	2.525
NAPS	7	0	2.382	2.270	3.145
reported	7	0	2.402	2.235	2.751

H = 11.866 with 6 degrees of freedom. ($P = 0.065$)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference ($P = 0.065$)

Spearman Rank Order Correlation

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	HFAX-032	HFAX-033	HFAX-034	HFAX-036	NAPS	reported
HFAX-031	0.857	0.857	0.714	0.214	0.929	0.429
	0.006	0.006	0.055	0.602	0.000	0.297
	7	7	7	7	7	7
HFAX-032		0.786	0.857	0.357	0.857	0.786
		0.025	0.006	0.388	0.006	0.025
		7	7	7	7	7
HFAX-033			0.857	0.571	0.964	0.286
			0.006	0.150	0.000	0.491
			7	7	7	7
HFAX-034				0.714	0.893	0.643
				0.055	0.000	0.096
				7	7	7
HFAX-036					0.536	0.214
					0.181	0.602
					7	7
NAPS						0.429
						0.297
						7

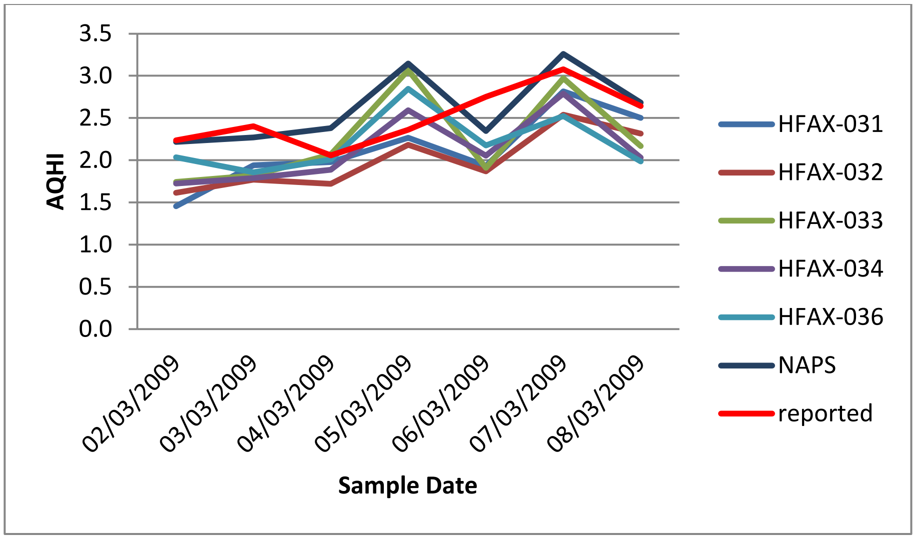

Figure 52. Time series of AQHI values for week six of the winter sampling campaign.

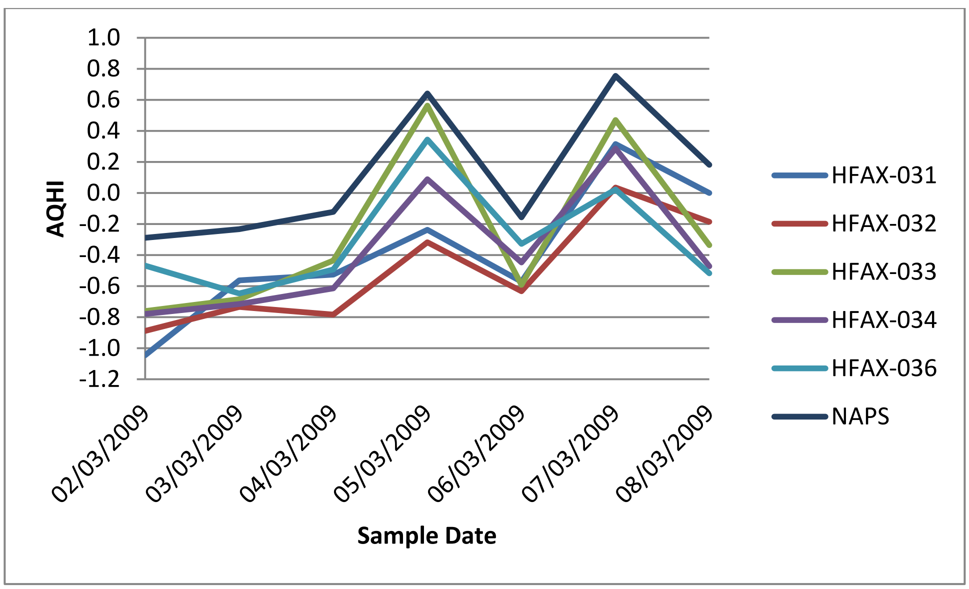

Figure 53. There is strong deviation from the reported values during the strong variation in AQHI.

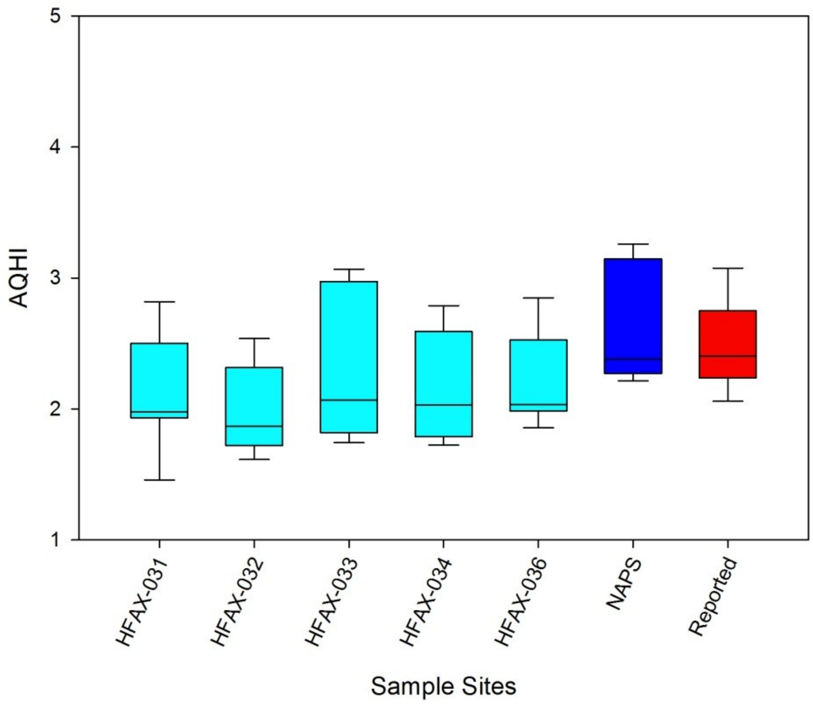

Figure 54. Box plot of AQHI for sample week six, wither sampling campaign.

WEEK SEVEN, WINTER SAMPLING CAMPAIGN (MARCH 12 TO MARCH 18, 2009)

In both the times series and deviation plots the calculated AQHI values do not show large variation (Figures. 19 and 20). AQHI values range from a maximum of 2.96 to a minimum of 1.71 with a median of 2.28. A few sample sites show some co variation while the reported AQHI stays consistent. Dominant wind patterns are from the South West and the west by north west (Figure. 22).

Kruskal-Wallis ANOVA was conducted and demonstrated a significant difference between the sample groups, Tukey's Test was then used to identify which groups were different. Two sample sites were significantly different from the reported AQHI values. The Spearman Rank Order Correlation method was used showing little correlation:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
HFAX-0377		0	2.071	2.046	2.286
HFAX-0387		0	2.370	2.067	2.589
HFAX-0407		0	1.968	1.891	2.282
HFAX-0417		0	2.515	1.926	2.594
HFAX-0427		0	1.949	1.889	2.043
NAPS	7	0	2.732	2.415	2.815
reported	7	0	2.722	2.572	2.849

H = 24.687 with 6 degrees of freedom. ($P = <0.001$)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P = <0.001$)

All Pairwise Multiple Comparison Procedures (Tukey's Test):

Comparison	**Diff of Ranks**	**q**	**P<0.05**
reported vs HFAX-042	210.000	5.555	Yes
reported vs HFAX-040	186.000	4.920	Yes
reported vs HFAX-037	143.000	3.783	No
reported vs HFAX-041	102.000	2.698	Do Not Test
reported vs HFAX-038	97.000	2.566	Do Not Test
reported vs NAPS	32.000	0.846	Do Not Test
NAPS vs HFAX-042	178.000	4.708	Yes
NAPS vs HFAX-040	154.000	4.074	No
NAPS vs HFAX-037	111.000	2.936	Do Not Test
NAPS vs HFAX-041	70.000	1.852	Do Not Test
NAPS vs HFAX-038	65.000	1.719	Do Not Test
HFAX-038 vs HFAX-042	113.000	2.989	No
HFAX-038 vs HFAX-040	89.000	2.354	Do Not Test
HFAX-038 vs HFAX-037	46.000	1.217	Do Not Test
HFAX-038 vs HFAX-041	5.000	0.132	Do Not Test
HFAX-041 vs HFAX-042	108.000	2.857	Do Not Test
HFAX-041 vs HFAX-040	84.000	2.222	Do Not Test
HFAX-041 vs HFAX-037	41.000	1.085	Do Not Test
HFAX-037 vs HFAX-042	67.000	1.772	Do Not Test
HFAX-037 vs HFAX-040	43.000	1.137	Do Not Test
HFAX-040 vs HFAX-042	24.000	0.635	Do Not Test

Spearman Rank Order Correlation

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	HFAX-038	HFAX-040	HFAX-041	HFAX-042	NAPS	reported
HFAX-037	0.143	0.321	0.464	0.750	0.571	0.214
	0.720	0.438	0.255	0.038	0.150	0.602
	7	7	7	7	7	7
HFAX-038		-0.143	-0.143	-0.393	0.393	0.821
		0.720	0.720	0.341	0.341	0.015
		7	7	7	7	7
HFAX-040			-0.429	0.607	-0.107	-0.429
			0.297	0.121	0.781	0.297
			7	7	7	7
HFAX-041				0.429	0.679	0.0714
				0.297	0.074	0.843
				7	7	7
HFAX-042					0.393	-0.393
					0.341	0.341
					7	7
NAPS						0.429
						0.297
						7

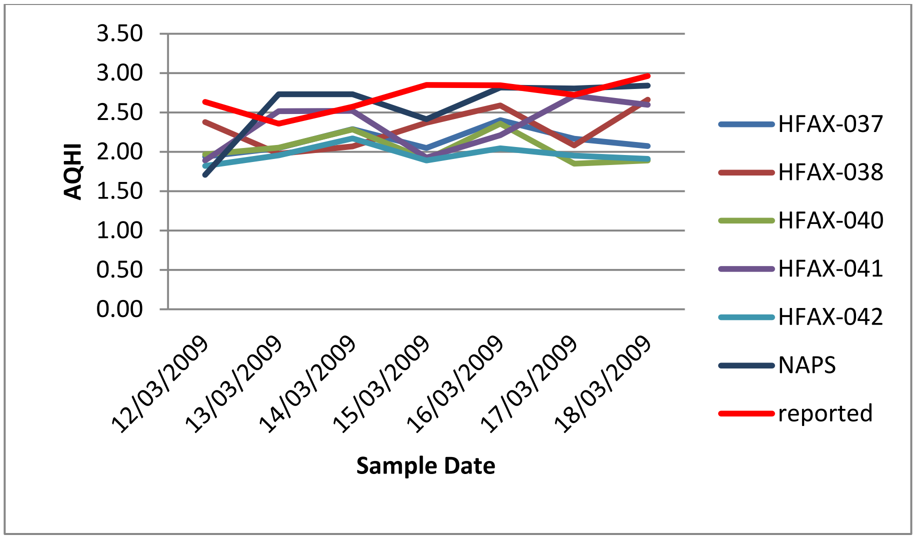

Figure 55. Time series of week seven of the winter sampling

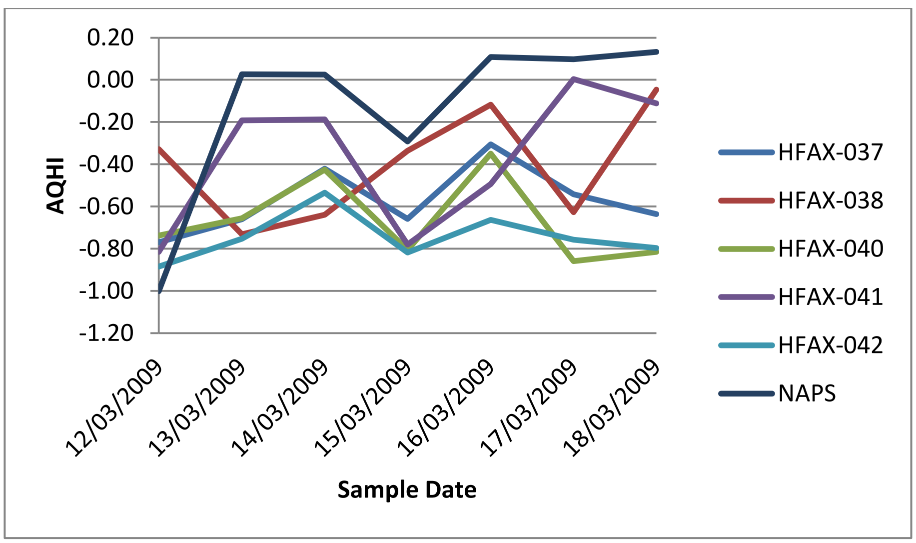

Figure 56. A time series plot showing the deviation of the sampling sites AQHI from the reported AQHI values

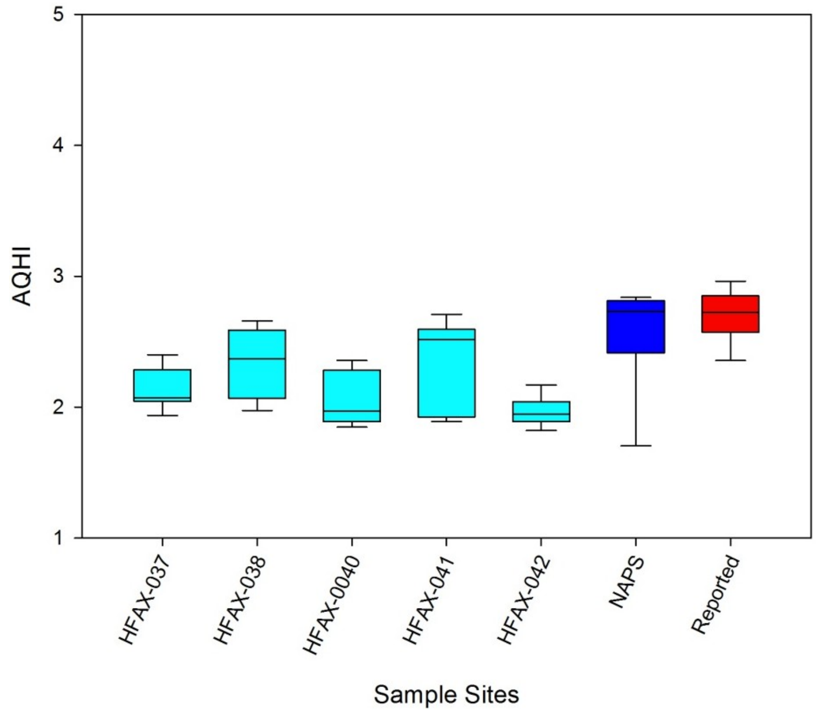

Figure 57. Box plot of the AQHI values for sample week seven of the winter sampling campaign

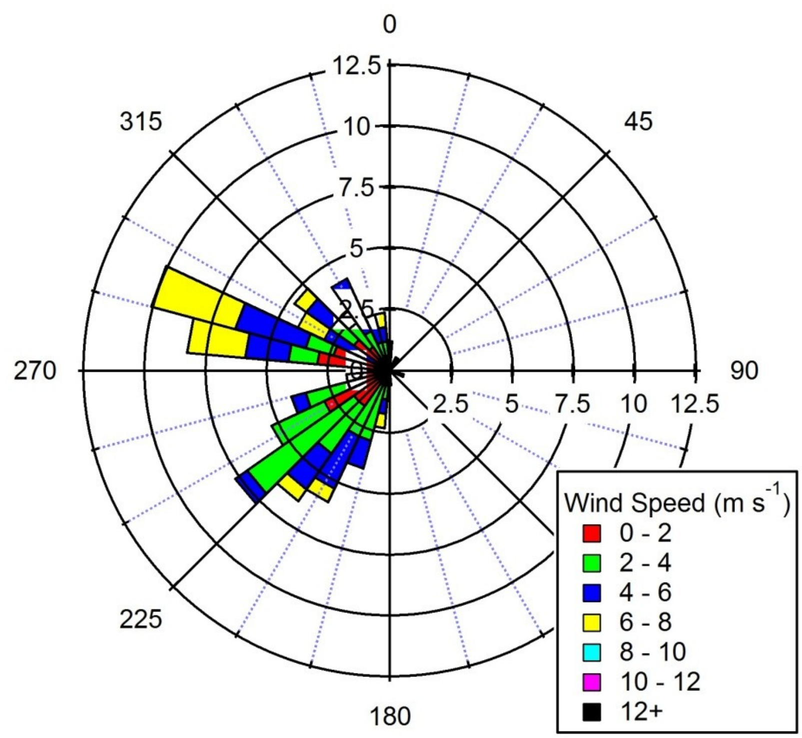

Figure 58. Wind rose plot for sample week seven of the winter sampling campaign

Week eight, winter sampling campaign (March 23 to March 29, 2009)

The weekly AQHI tire series shows a strong city trend that is not reflected by the reported AQHI values which stayed consistent through the sampling week (Figure. 23). The deviation from the reported AQHI demonstrates a city wide deviation from the reported AQHI values (Figure. 24). The weekly wind rose (Figure.26) demonstrates an unusual North by North West trend in wind and the AQHI reached a maximum of 4.43 with a minimum of 1.58 and median of 2.12.

Statistics were calculated using Kruskal-Wallis One Way ANOVA and Dunn's method of multiple comparison due to missing data., A secondary analysis was conducted after removing the sample site which was missing data to test multiple comparisons using the Tukey's Test. Correlation coefficients were calculated using the Spearman Rank Order method:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	**N**	**Missing**	**Median**	**25%**	**75%**
HFAX-0437		0	2.123	1.721	2.775
HFAX-0447		0	2.514	1.848	2.969
HFAX-0457		0	1.947	1.731	2.388
HFAX-0467		0	1.987	1.737	2.279
HFAX-0477		0	1.813	1.791	2.618
HFAX-0487		0	1.768	1.761	1.887
NAPS	6	0	2.559	2.175	3.769
reported	7	0	3.182	2.991	3.456

H = 21.835 with 7 degrees of freedom. (P = 0.003)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.003)

All Pairwise Multiple Comparison Procedures (Dunn's Method)

Comparison	**Diff of Ranks**	**Q**	**P<0.05**
reported vs HFAX-048	31.000	3.620	Yes
reported vs HFAX-047	26.429	3.086	No
reported vs HFAX-043	26.000	3.036	Do Not Test
reported vs HFAX-046	25.429	2.969	Do Not Test
reported vs HFAX-045	25.143	2.936	Do Not Test
reported vs HFAX-044	15.143	1.768	Do Not Test
reported vs NAPS	8.024	0.900	Do Not Test
NAPS vs HFAX-048	22.976	2.578	No
NAPS vs HFAX-047	18.405	2.065	Do Not Test
NAPS vs HFAX-043	17.976	2.017	Do Not Test
NAPS vs HFAX-046	17.405	1.953	Do Not Test
NAPS vs HFAX-045	17.119	1.921	Do Not Test
NAPS vs HFAX-044	7.119	0.799	Do Not Test
HFAX-044 vs HFAX-048	15.857	1.852	Do Not Test
HFAX-044 vs HFAX-047	11.286	1.318	Do Not Test
HFAX-044 vs HFAX-043	10.857	1.268	Do Not Test
HFAX-044 vs HFAX-046	10.286	1.201	Do Not Test
HFAX-044 vs HFAX-045	10.000	1.168	Do Not Test
HFAX-045 vs HFAX-048	5.857	0.684	Do Not Test
HFAX-045 vs HFAX-047	1.286	0.150	Do Not Test
HFAX-045 vs HFAX-043	0.857	0.100	Do Not Test
HFAX-045 vs HFAX-046	0.286	0.0334	Do Not Test
HFAX-046 vs HFAX-048	5.571	0.651	Do Not Test
HFAX-046 vs HFAX-047	1.000	0.117	Do Not Test

HFAX-046 vs HFAX-043	0.571	0.0667	Do Not Test
HFAX-043 vs HFAX-048	5.000	0.584	Do Not Test
HFAX-043 vs HFAX-047	0.429	0.0500	Do Not Test
HFAX-047 vs HFAX-048	4.571	0.534	Do Not Test

Secondary analysis:

Normality Test (Shapiro-Wilk) Failed (P < 0.050)

Kruskal-Wallis One Way Analysis of Variance on Ranks Wednesday, July 13, 2011, 11:56:28 AM

Group	**N**	**Missing**	**Median**	**25%**	**75%**
HFAX-043	7	0	2.123	1.721	2.775
HFAX-044	7	0	2.514	1.848	2.969
HFAX-045	7	0	1.947	1.731	2.388
HFAX-046	7	0	1.987	1.737	2.279
HFAX-047	7	0	1.813	1.791	2.618
HFAX-048	7	0	1.768	1.761	1.887
reported	7	0	3.182	2.991	3.456

H = 17.794 with 6 degrees of freedom. (P = 0.007)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.007)

All Pairwise Multiple Comparison Procedures (Tukey's Test):

Comparison	Diff of Ranks	q	P<0.05
reported vs HFAX-048	192.000	5.079	Yes
reported vs HFAX-047	162.000	4.285	Yes
reported vs HFAX-043	162.000	4.285	Yes
reported vs HFAX-046	155.000	4.100	No
reported vs HFAX-045	154.000	4.074	Do Not Test
reported vs HFAX-044	92.000	2.434	Do Not Test
HFAX-044 vs HFAX-048	100.000	2.645	No
HFAX-044 vs HFAX-047	70.000	1.852	Do Not Test
HFAX-044 vs HFAX-043	70.000	1.852	Do Not Test
HFAX-044 vs HFAX-046	63.000	1.666	Do Not Test
HFAX-044 vs HFAX-045	62.000	1.640	Do Not Test
HFAX-045 vs HFAX-048	38.000	1.005	Do Not Test
HFAX-045 vs HFAX-047	8.000	0.212	Do Not Test
HFAX-045 vs HFAX-043	8.000	0.212	Do Not Test
HFAX-045 vs HFAX-046	1.000	0.0265	Do Not Test
HFAX-046 vs HFAX-048	37.000	0.979	Do Not Test
HFAX-046 vs HFAX-047	7.000	0.185	Do Not Test
HFAX-046 vs HFAX-043	7.000	0.185	Do Not Test
HFAX-043 vs HFAX-048	30.000	0.794	Do Not Test
HFAX-043 vs HFAX-047	0.000	0.000	Do Not Test
HFAX-047 vs HFAX-048	30.000	0.794	Do Not Test

Pearson Product Moment Correlation

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	HFAX-044	HFAX-045	HFAX-046	HFAX-047	HFAX-048	NAPS	reported
HFAX-043	0.948 0.00116 7	0.844 0.0169 7	0.900 0.00568 7	0.929 0.00247 7	0.588 0.165 7	0.554 0.254 6	0.922 0.00317 7
HFAX-044		0.848 0.0159 7	0.906 0.00497 7	0.792 0.0338 7	0.656 0.109 7	0.457 0.363 6	0.771 0.0425 7
HFAX-045			0.970 0.000303 7	0.841 0.0177 7	0.915 0.00391 7	0.0284 0.957 6	0.752 0.0514 7
HFAX-046				0.851 0.0153 7	0.841 0.0177 7	0.175 0.740 6	0.814 0.0258 7
HFAX-047					0.624 0.134 7	0.432 0.392 6	0.924 0.00295 7
HFAX-048						-0.307 0.555 6	0.441 0.322 7
NAPS							0.542 0.266 6

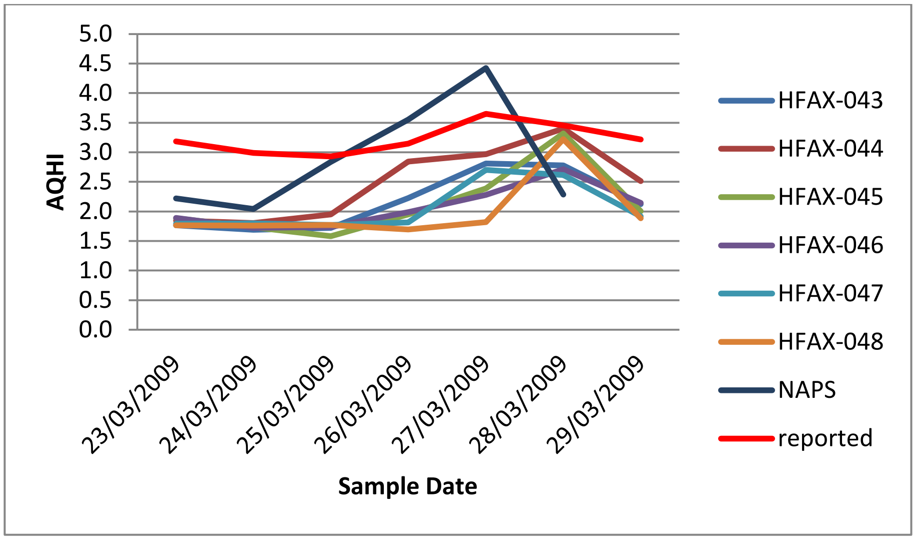

Figure 59. Time series plot of AQHI values for the sample week.

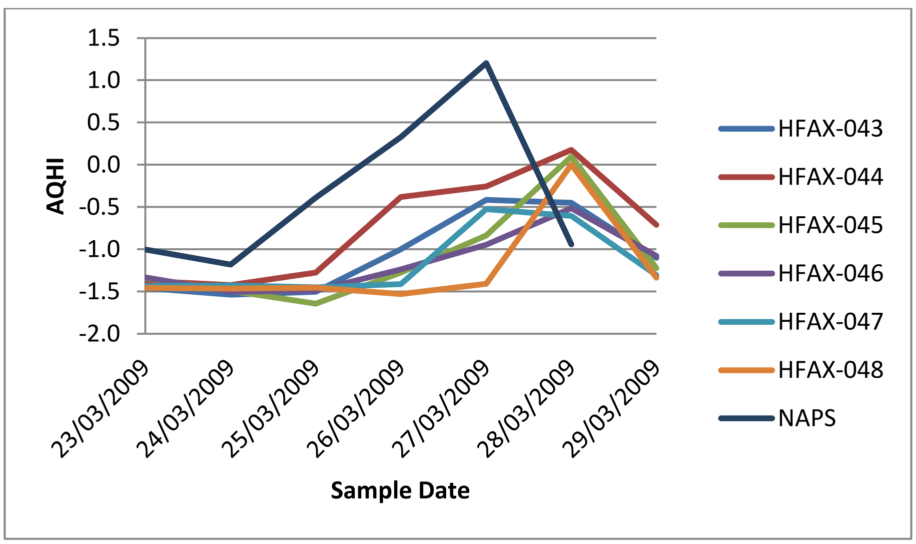

Figure 60. Deviation from the normalized reported AQHI for sample week eight of the winter sampling campaign.

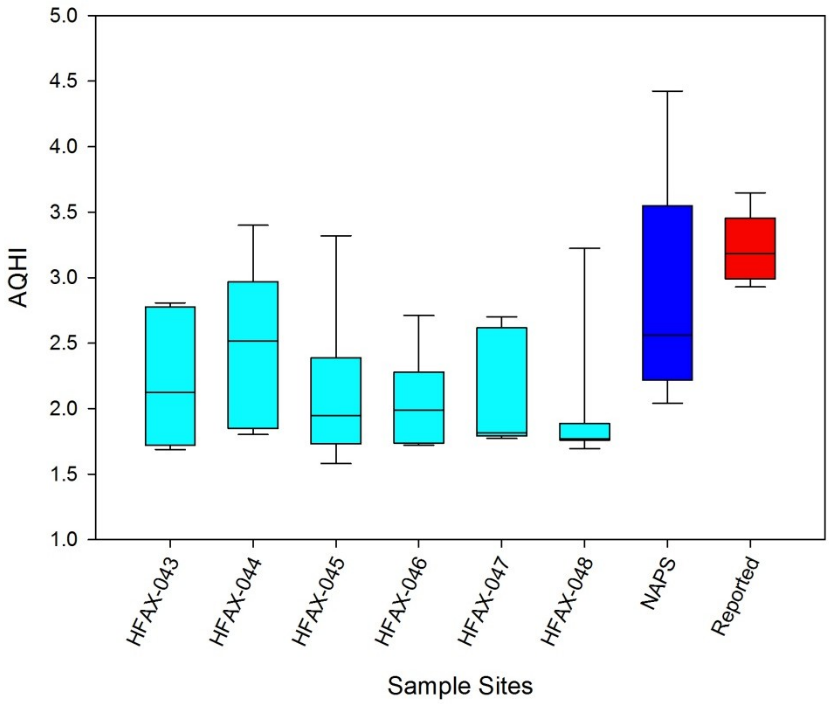

Figure 61. Box plot of the AQHI values for sample week eight of the winter sampling campaign.

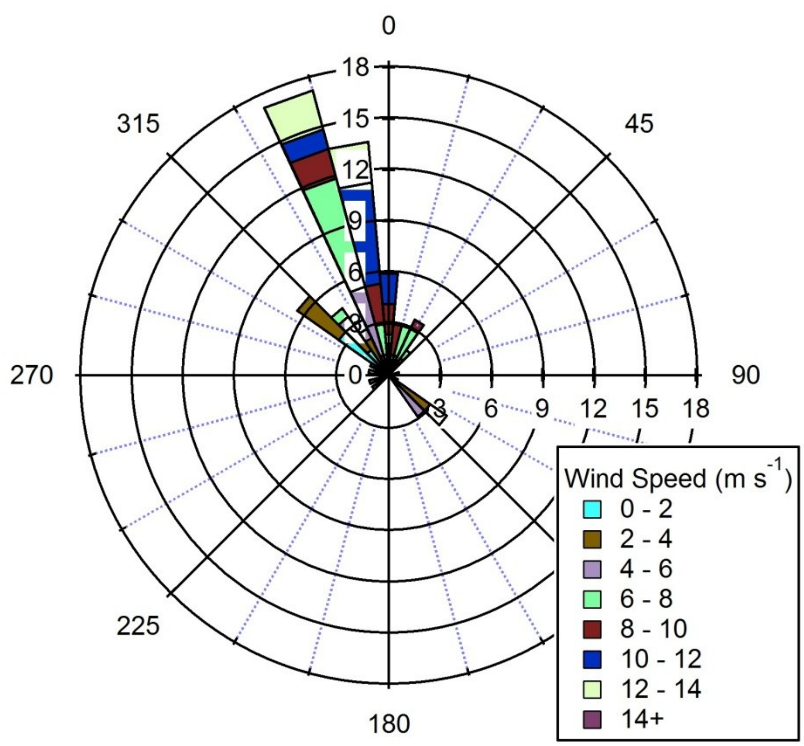

Figure 62. Wind rose plot for sample week eight of the winter sampling campaign.

Week nine, winter sampling campaign (April 4 to April 8, 2009)

During week nine of the winter sampling campaign, the city shows a strong and consistent pattern different than that of the reported AQHI values (Figures. 27). Deviation from the reported AQHI is likewise consistent over the sampling period (Figure. 28). The dominant wind component is from the South East (Figure. 30) and AQHI values are unusually consistent (Figure. 29) with a maximum of 4.04, minimum of 1.65 and median of 2.19.

Kruskal-Wallis ANOVA was used to test the variation in the sample groups, and Dunn's method for multiple comparisons with one of the treatment groups is unequal was used and identified two sample sites that differed from the reported AQHI values. A secondary analysis was conducted removing the sample site missing data. The Spearman Rank Order Correlation method was used for correlation coefficients:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
HFAX-0497		0	2.010	1.998	2.304
HFAX-0507		0	2.363	2.262	2.517
HFAX-0517		0	1.893	1.805	1.916
HFAX-0527		0	2.064	1.886	2.094
HFAX-0537		0	2.085	1.961	2.292
HFAX-0546		0	2.291	2.078	2.527
NAPS	7	0	2.802	2.584	2.949
reported	7	0	3.036	3.028	3.155

$H = 39.535$ with 7 degrees of freedom. ($P = <0.001$)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P = <0.001$)

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	**Diff of Ranks**	**Q**	**P<0.05**
reported vs HFAX-051	41.857	4.888	Yes
reported vs HFAX-052	31.714	3.703	Yes
reported vs HFAX-049	26.286	3.070	No
reported vs HFAX-053	25.857	3.019	Do Not Test
reported vs HFAX-054	18.500	2.076	Do Not Test
reported vs HFAX-050	13.286	1.551	Do Not Test
reported vs NAPS	2.286	0.267	Do Not Test
NAPS vs HFAX-051	39.571	4.621	Yes
NAPS vs HFAX-052	29.429	3.437	Yes
NAPS vs HFAX-049	24.000	2.803	Do Not Test
NAPS vs HFAX-053	23.571	2.753	Do Not Test
NAPS vs HFAX-054	16.214	1.819	Do Not Test
NAPS vs HFAX-050	11.000	1.285	Do Not Test
HFAX-050 vs HFAX-051	28.571	3.336	Yes
HFAX-050 vs HFAX-052	18.429	2.152	No
HFAX-050 vs HFAX-049	13.000	1.518	Do Not Test
HFAX-050 vs HFAX-053	12.571	1.468	Do Not Test
HFAX-050 vs HFAX-054	5.214	0.585	Do Not Test
HFAX-054 vs HFAX-051	23.357	2.621	No
HFAX-054 vs HFAX-052	13.214	1.483	Do Not Test
HFAX-054 vs HFAX-049	7.786	0.874	Do Not Test
HFAX-054 vs HFAX-053	7.357	0.825	Do Not Test
HFAX-053 vs HFAX-051	16.000	1.868	Do Not Test
HFAX-053 vs HFAX-052	5.857	0.684	Do Not Test
HFAX-053 vs HFAX-049	0.429	0.0500	Do Not Test

HFAX-049 vs HFAX-051	15.571	1.818	Do Not Test
HFAX-049 vs HFAX-052	5.429	0.634	Do Not Test
HFAX-052 vs HFAX-051	10.143	1.184	Do Not Test

Secondary analysis:

Normality Test (Shapiro-Wilk) Failed (P < 0.050)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
HFAX-049	7	0	2.010	1.998	2.304
HFAX-050	7	0	2.363	2.262	2.517
HFAX-051	7	0	1.893	1.805	1.916
HFAX-052	7	0	2.064	1.886	2.094
HFAX-053	7	0	2.085	1.961	2.292
NAPS	7	0	2.802	2.584	2.949
reported	7	0	3.036	3.028	3.155

H = 36.25 with 6 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

All Pairwise Multiple Comparison Procedures (Tukey's Test):

Comparison	Diff of Ranks	q	P<0.05
reported vs HFAX-051	254.000	6.719	Yes
reported vs HFAX-052	190.000	5.026	Yes
reported vs HFAX-049	156.000	4.127	No
reported vs HFAX-053	155.000	4.100	Do Not Test
reported vs HFAX-050	82.000	2.169	Do Not Test
reported vs NAPS	17.000	0.450	Do Not Test

NAPS vs HFAX-051	237.000	6.269	Yes
NAPS vs HFAX-052	173.000	4.576	Yes
NAPS vs HFAX-049	139.000	3.677	Do Not Test
NAPS vs HFAX-053	138.000	3.650	Do Not Test
NAPS vs HFAX-050	65.000	1.719	Do Not Test
HFAX-050 vs HFAX-051	172.000	4.550	Yes
HFAX-050 vs HFAX-052	108.000	2.857	No
HFAX-050 vs HFAX-049	74.000	1.957	Do Not Test
HFAX-050 vs HFAX-053	73.000	1.931	Do Not Test
HFAX-053 vs HFAX-051	99.000	2.619	No
HFAX-053 vs HFAX-052	35.000	0.926	Do Not Test
HFAX-053 vs HFAX-049	1.000	0.0265	Do Not Test
HFAX-049 vs HFAX-051	98.000	2.592	Do Not Test
HFAX-049 vs HFAX-052	34.000	0.899	Do Not Test
HFAX-052 vs HFAX-051	64.000	1.693	Do Not Test

Spearman Rank Order Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-050	HFAX-051	HFAX-052	HFAX-053	HFAX-054	NAPS	reported
HFAX-049	-0.036	-0.286	0.036	0.000	0.086	0.107	-0.180
	0.905	0.491	0.905	0.968	0.919	0.781	0.660
	7	7	7	7	6	7	7
HFAX-050		0.750	0.464	0.964	0.886	0.571	-0.108
		0.038	0.255	0.000	0.033	0.150	0.781
		7	7	7	6	7	7
HFAX-051			0.786	0.714	0.943	0.536	0.018
			0.025	0.055	0.017	0.181	0.905
			7	7	6	7	7
HFAX-052				0.571	0.829	0.714	0.036
				0.150	0.058	0.055	0.905
				7	6	7	7
HFAX-053					0.943	0.714	-0.054
					0.017	0.055	0.843
					6	7	7
HFAX-054						0.886	0.143
						0.033	0.803
						6	6
NAPS							0.487
							0.217
							7

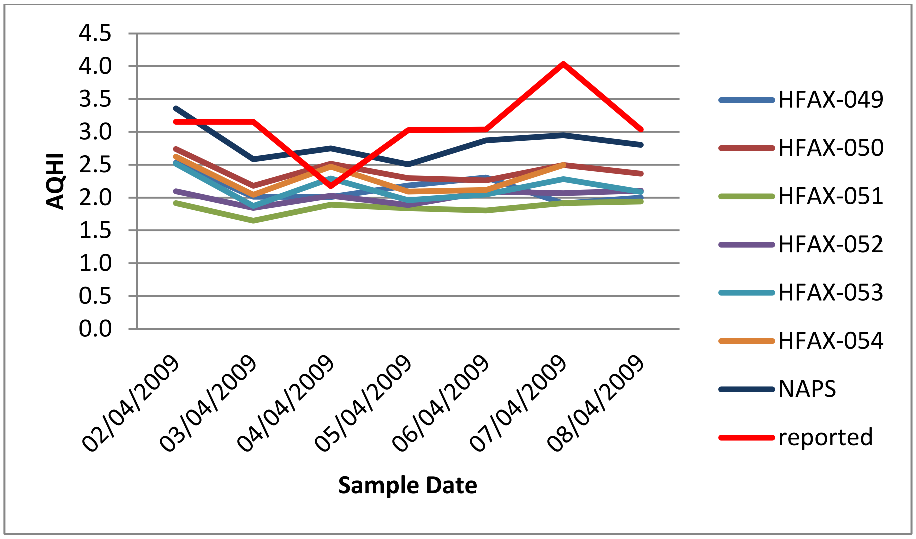

Figure 63. Time series plot of AQHI values for sample week nine of the winter sampling campaign.

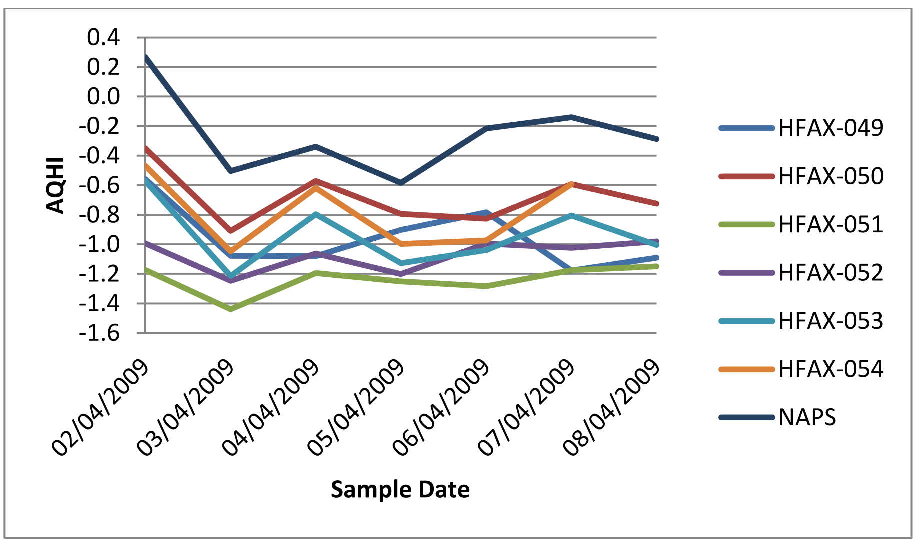

Figure 64.Time series of the deviation from the reported AQHI values for sample week nine of the winter campaign.

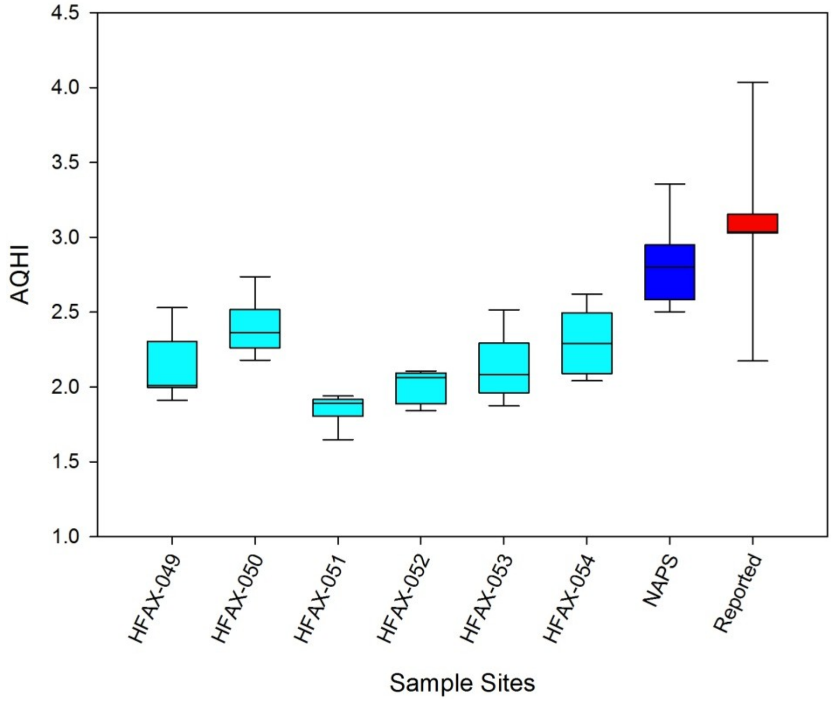

Figure 65. Box plot of AQHI values for sample week nine.

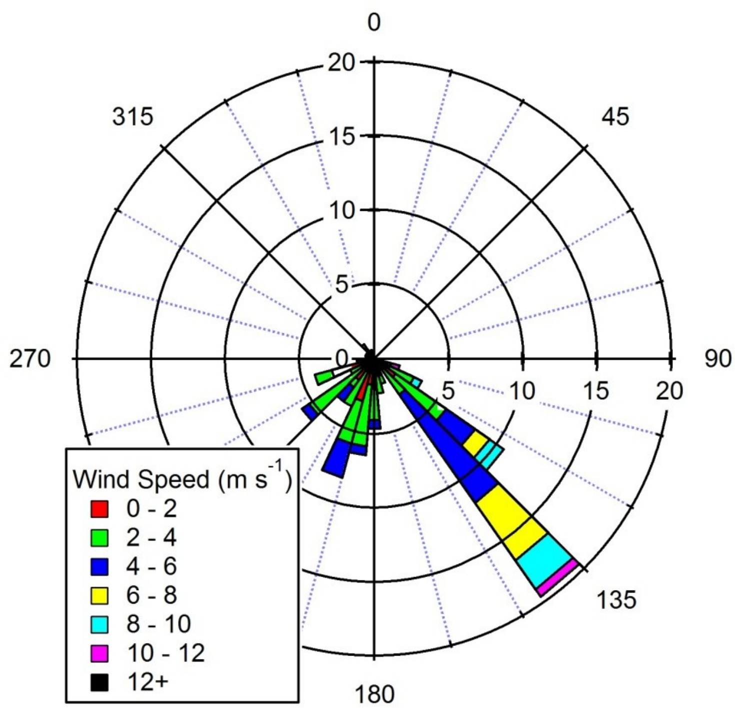

Figure 66. Wind rose plot of wind conditions for sampling week nine of the winter sampling campaign.

APPENDIX B: SUMMER SAMPLING CAMPAIGN

WEEK TWO, SUMMER SAMPLING CAMPAIGN (JUNE 29 TO JULY 5, 2009)

Week two of sampling during the summer campaign has low consistent AQHI levels through the week with a maximum of 2.11, minimum of 0.3 (below public reporting levels) and a median of 0.81. The reported AQHI is missing one data point however the time series shows similar patterns of AQHI levels for all sites with consistent deviation and low AQHI levels (Figures. 2 and 3). Wind conditions are low and from the South East as shown in Figure. 4.

Kruskal-Wallis ANOVA on ranks was conducted to test the difference in the median values of the sample groups, Dunn's Method was then used to identify differing groups, a secondary analysis could not be conducted because the reported AQHI was missing data. Spearman Rank Order Correlation was used to product correlation coefficients:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
HFAX-0057		0	0.855	0.645	0.983
HFAX-0377		0	0.853	0.828	1.168
HFAX-0587		0	0.696	0.692	0.931
HFAX-0117		0	0.711	0.646	0.910
HFAX-0507		0	0.675	0.571	0.709
HFAX-0387		0	0.768	0.588	0.955
NAPS	7	0	1.232	1.066	1.338
Reported	7	1	1.658	1.138	1.809

H = 22.702 with 7 degrees of freedom. (P = 0.002)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.002)

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	**Diff of Ranks**	**Q**	**P<0.05**
Reported vs HFAX-050	28.595	3.208	Yes
Reported vs HFAX-011	23.595	2.647	No
Reported vs HFAX-038	23.024	2.583	Do Not Test
Reported vs HFAX-058	23.024	2.583	Do Not Test
Reported vs HFAX-005	19.024	2.134	Do Not Test
Reported vs HFAX-037	9.452	1.060	Do Not Test
Reported vs NAPS	0.310	0.0347	Do Not Test
NAPS vs HFAX-050	28.286	3.303	Yes
NAPS vs HFAX-011	23.286	2.719	Do Not Test
NAPS vs HFAX-038	22.714	2.652	Do Not Test
NAPS vs HFAX-058	22.714	2.652	Do Not Test
NAPS vs HFAX-005	18.714	2.185	Do Not Test
NAPS vs HFAX-037	9.143	1.068	Do Not Test
HFAX-037 vs HFAX-050	19.143	2.235	No
HFAX-037 vs HFAX-011	14.143	1.652	Do Not Test
HFAX-037 vs HFAX-038	13.571	1.585	Do Not Test
HFAX-037 vs HFAX-058	13.571	1.585	Do Not Test
HFAX-037 vs HFAX-005	9.571	1.118	Do Not Test
HFAX-005 vs HFAX-050	9.571	1.118	Do Not Test
HFAX-005 vs HFAX-011	4.571	0.534	Do Not Test
HFAX-005 vs HFAX-038	4.000	0.467	Do Not Test
HFAX-005 vs HFAX-058	4.000	0.467	Do Not Test
HFAX-058 vs HFAX-050	5.571	0.651	Do Not Test
HFAX-058 vs HFAX-011	0.571	0.0667	Do Not Test

HFAX-058 vs HFAX-038	0.000	0.000	Do Not Test
HFAX-038 vs HFAX-050	5.571	0.651	Do Not Test
HFAX-038 vs HFAX-011	0.571	0.0667	Do Not Test
HFAX-011 vs HFAX-050	5.000	0.584	Do Not Test

Spearman Rank Order Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-037	**HFAX-058**	**HFAX-011**	**HFAX-050**	**HFAX-038**	**NAPS**	**Reported**
HFAX-005	0.964 0.000 7	0.571 0.150 7	0.429 0.297 7	0.179 0.660 7	0.643 0.096 7	0.643 0.096 7	0.486 0.356 6
HFAX-037		0.500 0.217 7	0.250 0.545 7	0.214 0.602 7	0.536 0.181 7	0.607 0.121 7	0.486 0.356 6
HFAX-058			0.500 0.217 7	0.286 0.491 7	0.250 0.545 7	0.286 0.491 7	0.200 0.714 6
HFAX-011				0.607 0.121 7	0.714 0.055 7	0.714 0.055 7	0.943 0.017 6
HFAX-050					0.500 0.217 7	0.750 0.038 7	0.943 0.017 6
HFAX-038						0.893 0.000 7	0.771 0.103 6
NAPS							0.943 0.017 6

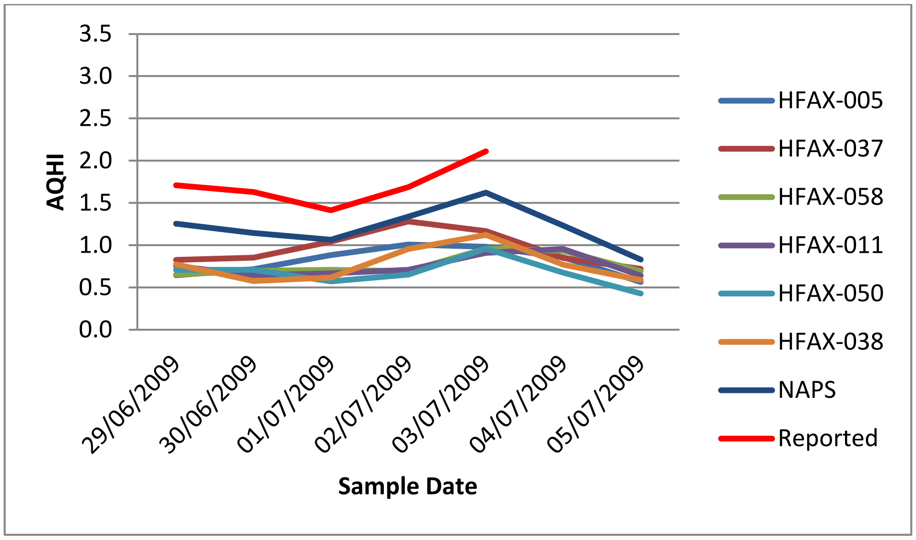

Figure 67. Time series of AQHI values for sample week two

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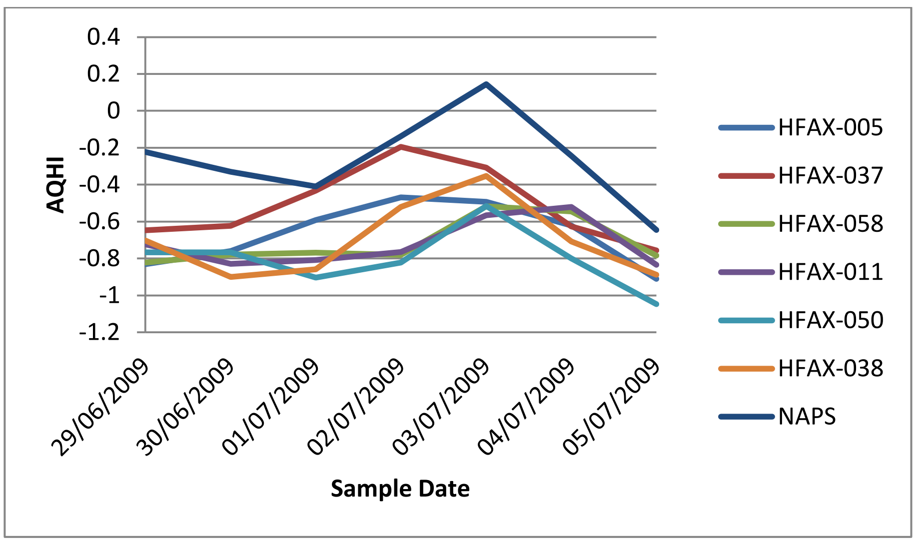

Figure 68. Deviations from the normalized reported AQHI values.

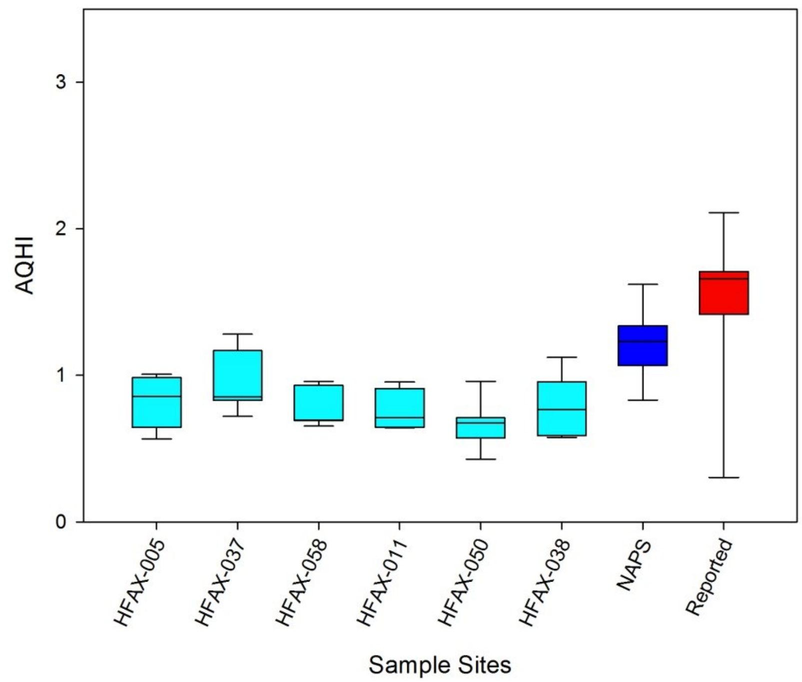

Figure 69. Box plot of AQHI values for sample week two of the summer sampling campaign.

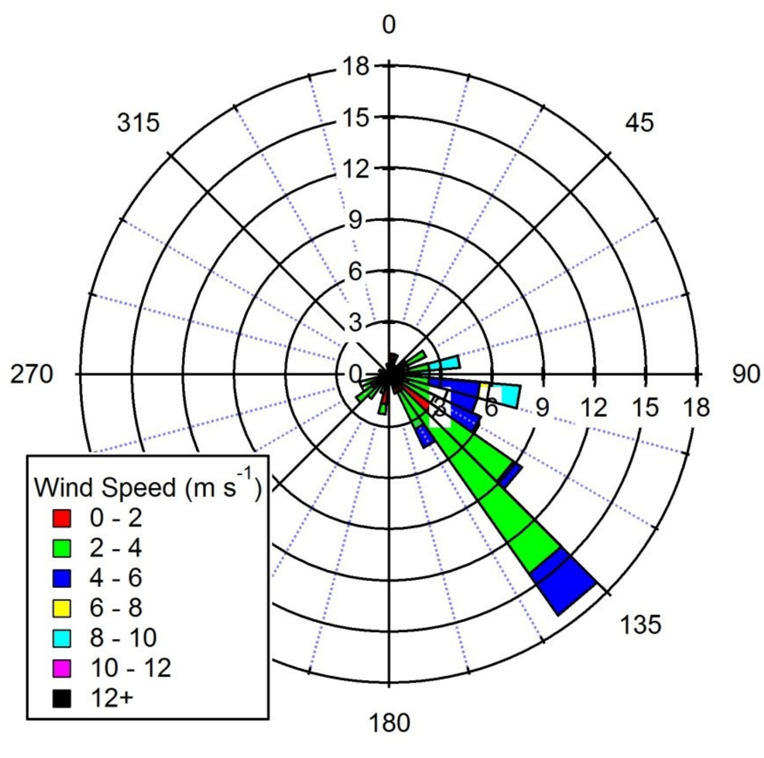

Figure 70. Wind rose plot of sample week two of the summer sampling campaign.

WEEK THREE, SUMMER SAMPLING CAMPAIGN (JULY 9 TO JULY 15, 2009)

Week three has consistent low AQHI values ranging from a minimum of 0.8 to a maximum of 2.1 with a median of 1. The sample sites across the city are similar across the sample sites (Figure. 5). Deviations from the normal are also consistent and low reflecting the general shape of sampling data (Figure. 6). Weekly winds are predominantly from the South East with a secondary components from the south west (Figure. 8).

Statistically, the data passed both the normality test and equal variance tests and was assessed using ANOVA and the Holm-Sidak method for multiple comparisons. All sample sites are significantly different from the reported AQHI value and the NAPS station. The correlation coefficients were calculated using Pearson Product Moment:

Normality Test (Shapiro-Wilk) Passed (P = 0.070)

Equal Variance Test: Passed (P = 0.094)

Group Name	**N**	**Missing**	**Mean**	**Std Dev**	**SEM**
HFAX-040	7	0	1.023	0.0876	0.0331
HFAX-031	7	0	1.097	0.160	0.0605
HFAX-007	7	0	0.932	0.0898	0.0339
HFAX-053	7	0	0.938	0.174	0.0657
HFAX-046	7	0	0.957	0.0937	0.0354
NAPS	7	0	1.465	0.287	0.108
Reported	7	0	1.738	0.212	0.0800

Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Between Groups	6	4.146	0.691	23.320	<0.001

Residual	42	1.244	0.0296
Total	48	5.390	

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):

Overall significance level = 0.05

Comparisons for factor:

Comparison	**Diff of Means**	**t**	**P**	**P<0.050**
Reported vs. HFAX-007	0.806	8.763	<0.001	Yes
Reported vs. HFAX-053	0.800	8.695	<0.001	Yes
Reported vs. HFAX-046	0.781	8.492	<0.001	Yes
Reported vs. HFAX-040	0.715	7.769	<0.001	Yes
Reported vs. HFAX-031	0.642	6.974	<0.001	Yes
NAPS vs. HFAX-007	0.533	5.791	<0.001	Yes
NAPS vs. HFAX-053	0.527	5.723	<0.001	Yes
NAPS vs. HFAX-046	0.508	5.521	<0.001	Yes
NAPS vs. HFAX-040	0.441	4.798	<0.001	Yes
NAPS vs. HFAX-031	0.368	4.002	0.003	Yes
Reported vs. NAPS	0.273	2.972	0.052	No
HFAX-031 vs. HFAX-007	0.165	1.789	0.570	No
HFAX-031 vs. HFAX-053	0.158	1.721	0.583	No
HFAX-031 vs. HFAX-046	0.140	1.518	0.691	No
HFAX-040 vs. HFAX-007	0.0914	0.993	0.937	No
HFAX-040 vs. HFAX-053	0.0851	0.925	0.931	No
HFAX-031 vs. HFAX-040	0.0732	0.795	0.940	No
HFAX-040 vs. HFAX-046	0.0665	0.723	0.923	No
HFAX-046 vs. HFAX-007	0.0249	0.270	0.990	No

HFAX-046 vs. HFAX-053	0.0186	0.202	0.975	No
HFAX-053 vs. HFAX-007	0.00628	0.0682	0.946	No

Pearson Product Moment Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-031	**HFAX-007**	**HFAX-053**	**HFAX-046**	**NAPS**	**Reported**
HFAX-040	-0.196	-0.159	-0.820	-0.0661	-0.292	0.668
	0.673	0.734	0.024	0.888	0.525	0.101
	7	7	7	7	7	7
HFAX-031		0.881	0.442	0.973	0.863	-0.160
		0.008	0.321	0.000	0.012	0.732
		7	7	7	7	7
HFAX-007			0.491	0.813	0.785	0.114
			0.263	0.026	0.036	0.808
			7	7	7	7
HFAX-053				0.324	0.424	-0.224
				0.478	0.343	0.629
				7	7	7
HFAX-046					0.767	-0.0784
					0.044	0.867
					7	7
NAPS						-0.365
						0.420
						7

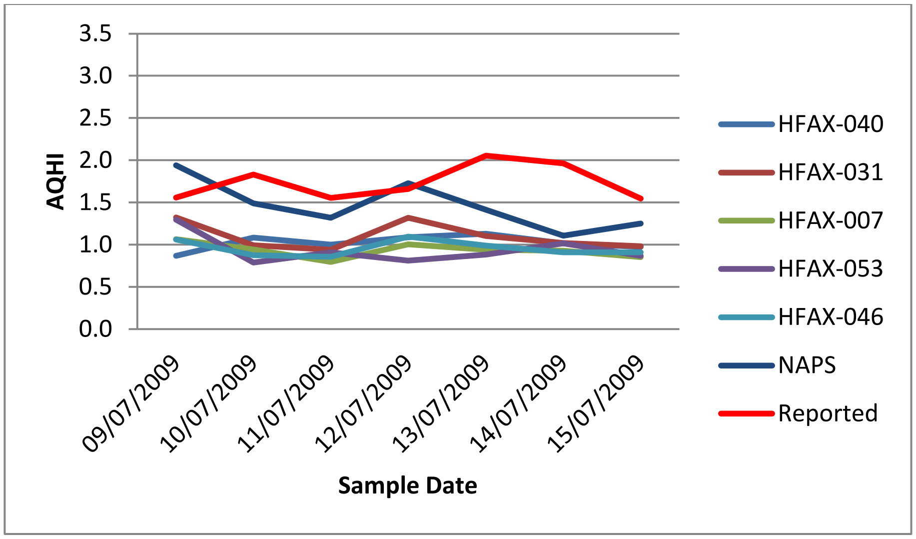

Figure 71. Time series of AQHI values for sample week three, summer campaign.

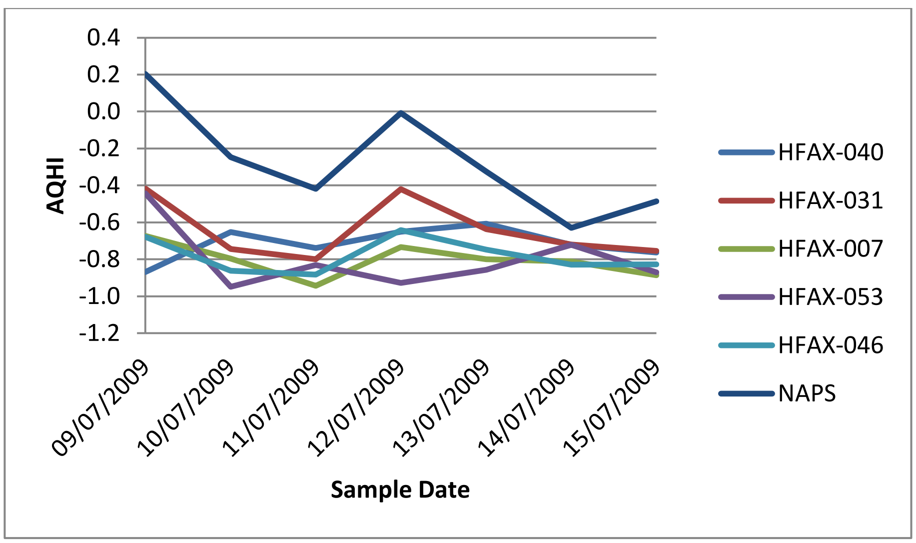

Figure 72. Deviation from the reported AQHI levels for sample week three

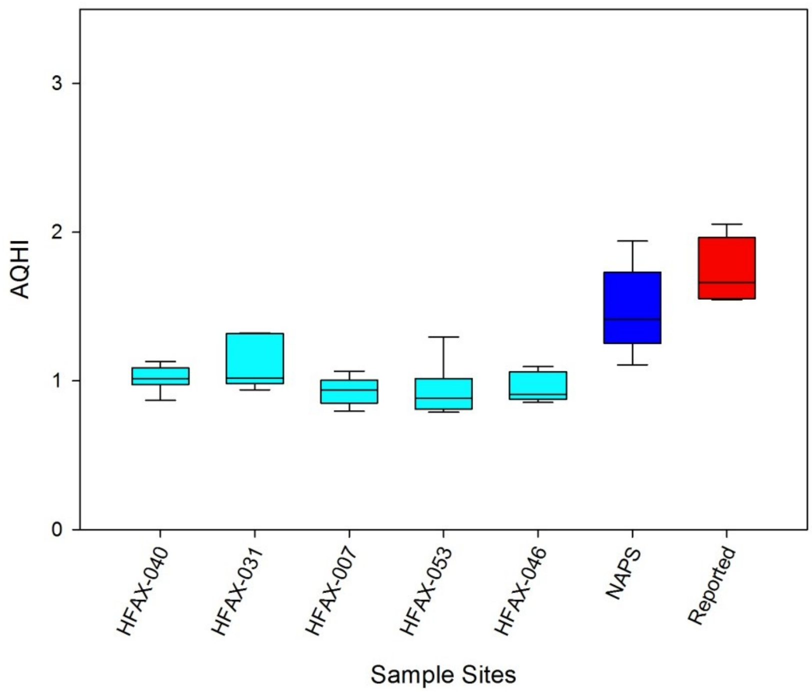

Figure 73. Box plot of AQHI values for this sample period.

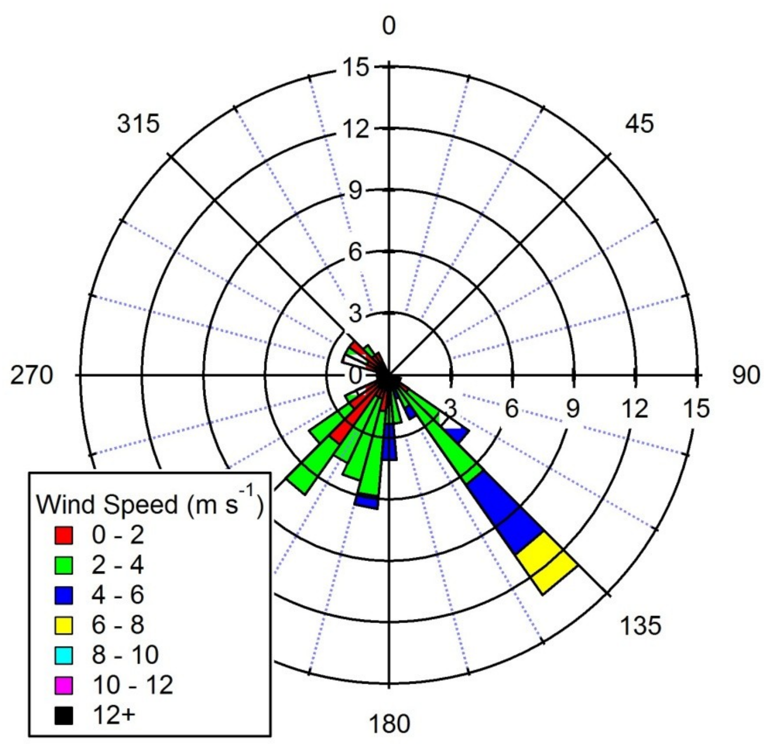

Figure 74. Wind rose plot of the wind condition for the sample week.

WEEK FOUR, SUMMER SAMPLING CAMPAIGN (JULY 20 TO JULY 26,2009)

The AQHI values for sample week four are similarly low with a median of 1.2 and a minimum of 0.8 and a maximum of 2.6. The weekly times series shows a common pattern between the sample sites, the reported AQHI shows the inverse pattern (Figure. 9). Deviation from the reported AQHI are minimal with the reported AQHI well representing the sampled AQHI (Figure. 10).

The weekly AQHI data failed the normality test requiring the use of Kruskal-Wallis AQNOVA on ranks and Tukey's Test for multiple comparisons. One site is significantly difference from the reported AQHI at a significance of 0.05. The Spearman Rank Order method was used to calculate correlation coefficients:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	N	Missing	Median	25%	75%
HFAX-0267		0	1.261	0.993	1.585
HFAX-0457		0	1.022	0.873	1.278
HFAX-0217		0	1.143	1.057	1.358
HFAX-0367		0	1.153	0.963	1.323
HFAX-0147		0	1.026	0.933	1.314
HFAX-0127		0	0.896	0.796	1.103
NAPS	7	0	1.492	1.232	1.948
Reported	7	0	1.475	1.147	1.803

$H = 20.178$ with 7 degrees of freedom. ($P = 0.005$)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P = 0.005$)

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparison	**Diff of Ranks**	**q**	**P<0.05**
NAPS vs HFAX-012	228.000	5.284	Yes
NAPS vs HFAX-045	170.000	3.940	No
NAPS vs HFAX-014	156.000	3.615	Do Not Test
NAPS vs HFAX-036	126.000	2.920	Do Not Test
NAPS vs HFAX-021	93.000	2.155	Do Not Test
NAPS vs HFAX-026	86.000	1.993	Do Not Test
NAPS vs Reported	41.000	0.950	Do Not Test
Reported vs HFAX-012	187.000	4.334	Yes
Reported vs HFAX-045	129.000	2.990	Do Not Test
Reported vs HFAX-014	115.000	2.665	Do Not Test
Reported vs HFAX-036	85.000	1.970	Do Not Test
Reported vs HFAX-021	52.000	1.205	Do Not Test
Reported vs HFAX-026	45.000	1.043	Do Not Test
HFAX-026 vs HFAX-012	142.000	3.291	No
HFAX-026 vs HFAX-045	84.000	1.947	Do Not Test
HFAX-026 vs HFAX-014	70.000	1.622	Do Not Test
HFAX-026 vs HFAX-036	40.000	0.927	Do Not Test
HFAX-026 vs HFAX-021	7.000	0.162	Do Not Test
HFAX-021 vs HFAX-012	135.000	3.129	Do Not Test
HFAX-021 vs HFAX-045	77.000	1.784	Do Not Test
HFAX-021 vs HFAX-014	63.000	1.460	Do Not Test
HFAX-021 vs HFAX-036	33.000	0.765	Do Not Test
HFAX-036 vs HFAX-012	102.000	2.364	Do Not Test
HFAX-036 vs HFAX-045	44.000	1.020	Do Not Test
HFAX-036 vs HFAX-014	30.000	0.695	Do Not Test
HFAX-014 vs HFAX-012	72.000	1.669	Do Not Test

HFAX-014 vs HFAX-045	14.000	0.324	Do Not Test
HFAX-045 vs HFAX-012	58.000	1.344	Do Not Test

Spearman Rank Order Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-045	**HFAX-021**	**HFAX-036**	**HFAX-014**	**HFAX-012**	**NAPS**	**Reported**
HFAX-026	0.497 0.210 7	0.336 0.416 7	0.767 0.026 7	0.982 0.000 7	0.731 0.039 7	0.393 0.335 7	0.533 0.174 7
HFAX-045		0.913 0.002 7	0.820 0.013 7	0.443 0.272 7	0.782 0.022 7	0.955 0.000 7	0.750 0.032 7
HFAX-021			0.840 0.009 7	0.303 0.465 7	0.834 0.010 7	0.970 0.000 7	0.515 0.192 7
HFAX-036				0.754 0.031 7	0.982 0.000 7	0.838 0.009 7	0.557 0.152 7
HFAX-014					0.732 0.039 7	0.363 0.377 7	0.430 0.287 7
HFAX-012						0.836 0.010 7	0.511 0.195 7
NAPS							0.666 0.071 7

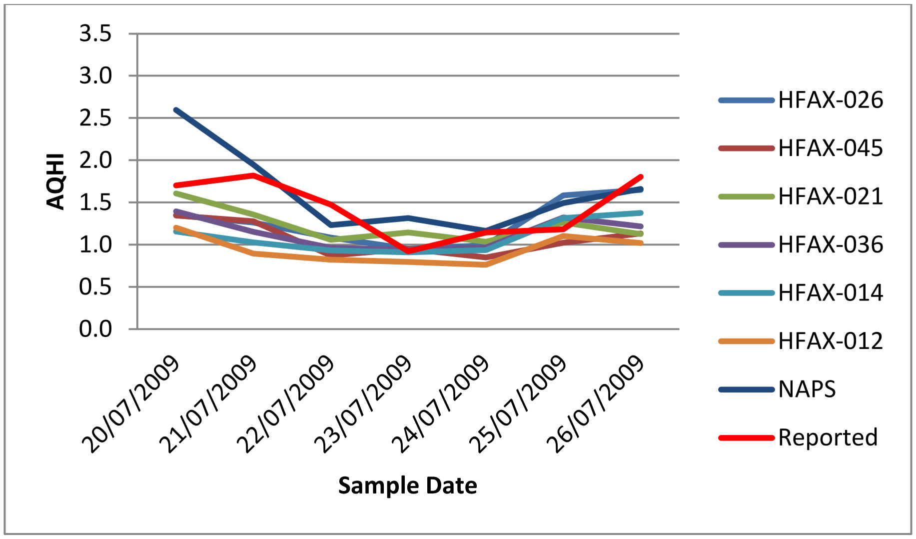

Figure 75. Time series of AQHI values for sample week four of the summer sampling campaign

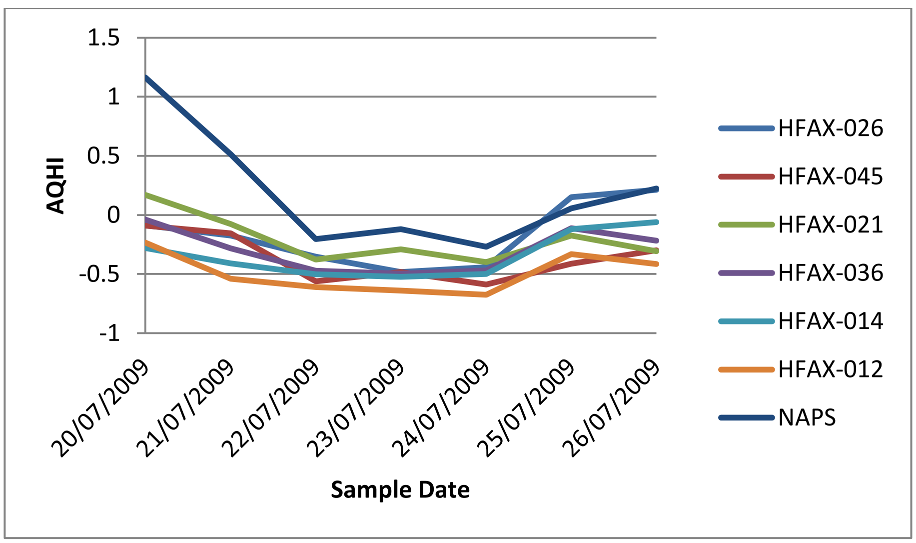

Figure 76. Deviation from the normalized reported AQHI values for sample week four.

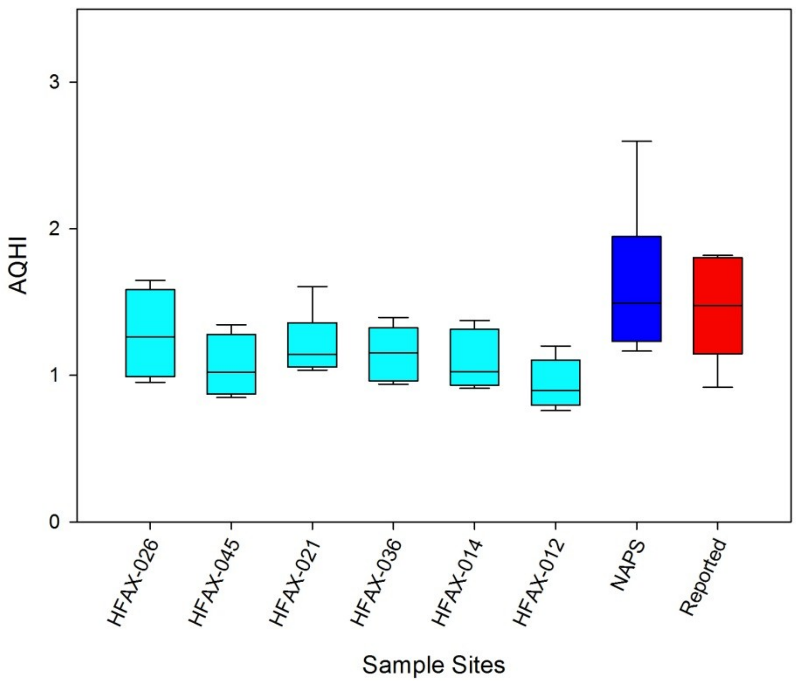

Figure 77. Box plot of AQHI values for sample week four of the summer sampling campaign.

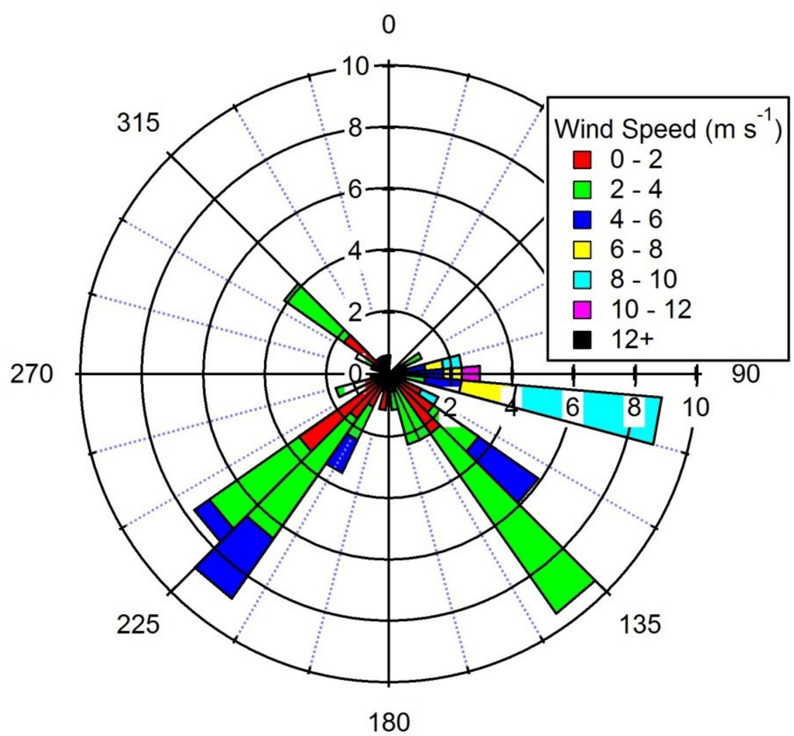

Figure 78. Wind rose plot of wind conditions for sample week four of the summer sampling campaign.

WEEK FIVE, SUMMER SAMPLING CAMPAIGN (JULY 30 TO AUGUST 5, 2009)

AQHI values range for week five range from 1.2 to 3 with a median values with 1.7, the sample site AQHI values follow a similar pattern through the sample week (Figure. 13) the deviation from the reported AQHI values across the week reflect the overall pattern of the sample week (Figure. 14). Two major wind components are demonstrated, one to each both the south east and west (Figure. 16).

The AQHI data was tested using Kruskal-Wallis ANOVA on ranks with identified statistically different groups that were tested using Tukey's Test for multiple comparisons. Three of the sample sites were identified as statically different from the reported values. Spearman's Rank Order Correlation method was used to calculate correlation coefficients:

Normality Test (Shapiro-Wilk) Failed (P < 0.050)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	**N**	**Missing**	**Median**	**25%**	**75%**
HFAX-0157		0	1.233	1.218	1.659
HFAX-0167		0	1.356	1.257	1.546
HFAX-0577		0	1.650	1.423	1.777
HFAX-0177		0	1.358	1.270	1.471
NAPS	7	0	2.077	1.733	2.545
Reported	7	0	2.022	1.845	2.139

H = 26.181 with 5 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

All Pairwise Multiple Comparison Procedures (Tukey's Test):

Comparison	**Diff of Ranks**	**q**	**P<0.05**
NAPS vs HFAX-015	158.000	4.868	Yes
NAPS vs HFAX-017	151.000	4.652	Yes
NAPS vs HFAX-016	146.000	4.498	Yes
NAPS vs HFAX-057	81.000	2.496	No
NAPS vs Reported	1.000	0.0308	Do Not Test
Reported vs HFAX-015	157.000	4.837	Yes
Reported vs HFAX-017	150.000	4.621	Yes
Reported vs HFAX-016	145.000	4.467	Yes
Reported vs HFAX-057	80.000	2.465	Do Not Test
HFAX-057 vs HFAX-015	77.000	2.372	No
HFAX-057 vs HFAX-017	70.000	2.157	Do Not Test
HFAX-057 vs HFAX-016	65.000	2.003	Do Not Test
HFAX-016 vs HFAX-015	12.000	0.370	Do Not Test
HFAX-016 vs HFAX-017	5.000	0.154	Do Not Test
HFAX-017 vs HFAX-015	7.000	0.216	Do Not Test

Spearman Rank Order Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-016	HFAX-057	HFAX-017	NAPS	Reported
HFAX-015	0.643	0.500	0.714	0.893	0.143
	0.096	0.217	0.055	0.000	0.720
	7	7	7	7	7
HFAX-016		0.500	0.643	0.679	0.143
		0.217	0.096	0.074	0.720
		7	7	7	7
HFAX-057			0.786	0.571	0.286
			0.025	0.150	0.491
			7	7	7
HFAX-017				0.679	0.571
				0.074	0.150
				7	7
NAPS					0.357
					0.388
					7

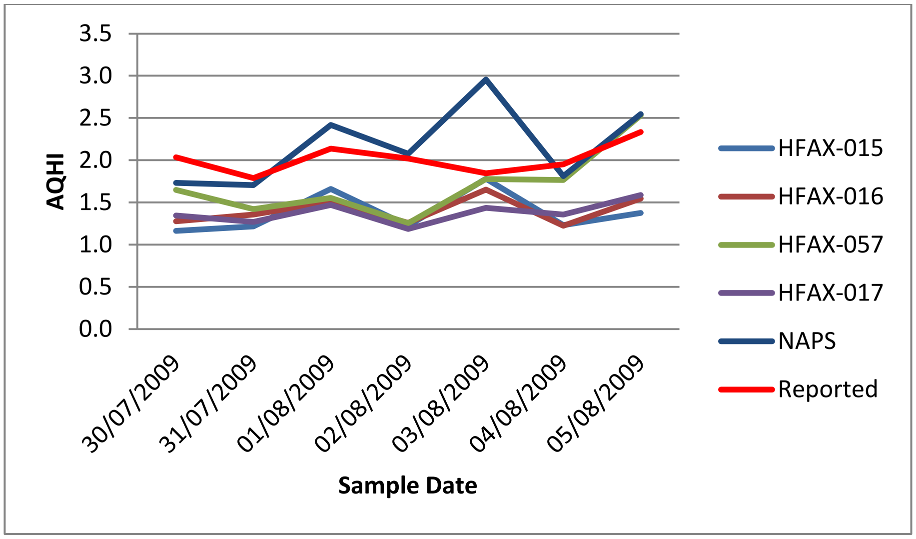

Figure 79. Time series of AQHI values for sample week five of the summer sampling campaign.

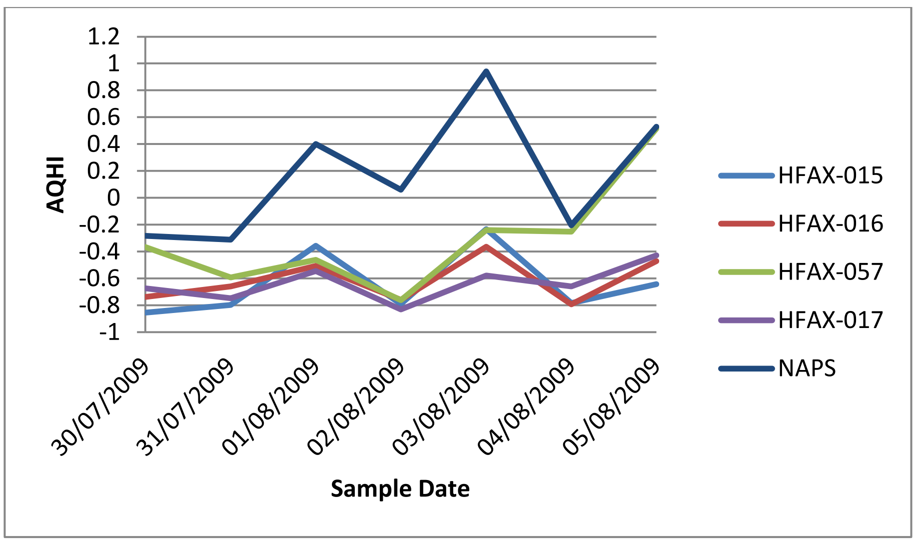

Figure 80. Times series of deviation from the normalized reported AQHI values .

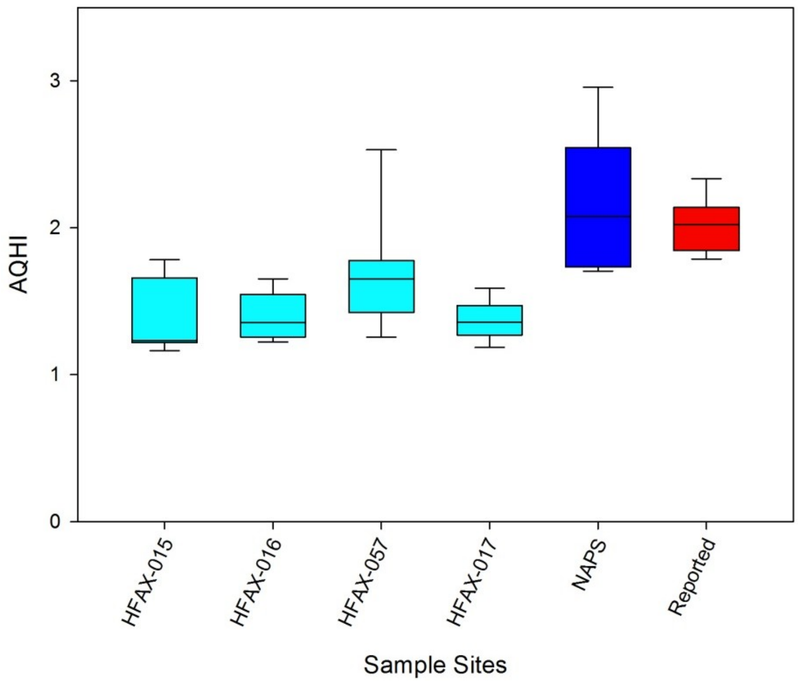

Figure 81. Box plot of AQHI values for sample week five of the summer sampling campaign.

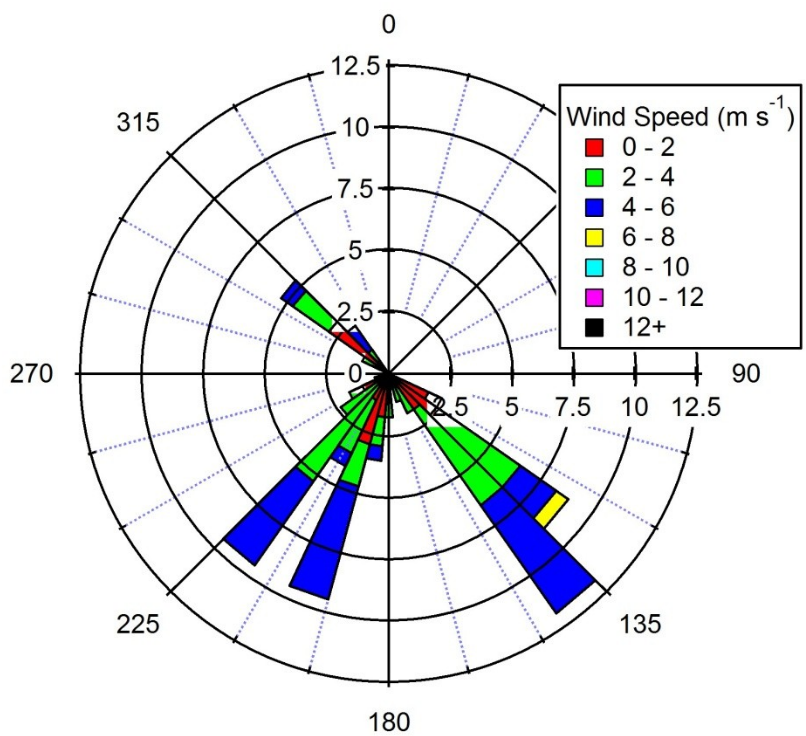

Figure 82. Wind rose plot of wind conditions for sample week five of the summer sampling campaign.

WEEK SIX, SUMMER SAMPLING CAMPAIGN (AUGUST 10 TO AUGUST16, 2009)

AQHI values from week six of the summer sampling season ranged from 0.9 to 2.9 with a median of 1.5. The time series demonstrates the reported AQHI values closely tracks the sample site values (Figure. 17) with low deviations (Figure. 18). NAPS site AQHI is significantly different from all other values from the sample period (Figure. 19). Wind conditions are predominantly from the South East with two secondary components to the south and North East.

The AQHI data was analyzed using ANOVA and Holm-Sidak method with two data point missing from one of the sample sites. All sample sites besides site HFAX-019 were statistically different from the reported AQHI. The correlation coefficients were calculated using the Pearson Product Moment Method:

Normality Test (Shapiro-Wilk) Passed ($P = 0.615$)

Equal Variance Test: Passed ($P = 0.193$)

Group Name	N	Missing	Mean	Std Dev	SEM
HFAX-019	7	0	1.230	0.227	0.0859
HFAX-052	7	0	1.344	0.189	0.0713
HFAX-022	7	0	1.483	0.284	0.107
HFAX-002	7	0	1.539	0.317	0.120
HFAX-028	7	0	1.509	0.283	0.107
HFAX-049	7	2	1.696	0.273	0.122
NAPS	7	0	2.415	0.430	0.162
Reported	7	0	1.630	0.208	0.0787

Source of Variation	DF	SS	MS	F	P
Between Groups	7	6.303	0.900	11.021	<0.001
Residual	46	3.758	0.0817		
Total	53	10.061			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):

Overall significance level = 0.05

Comparisons for factor:

Comparison	Diff of Means	t	P	P<0.050
NAPS vs. HFAX-019	1.185	7.759	<0.001	Yes
NAPS vs. HFAX-052	1.071	7.012	<0.001	Yes
NAPS vs. HFAX-022	0.932	6.101	<0.001	Yes
NAPS vs. HFAX-028	0.907	5.935	<0.001	Yes
NAPS vs. HFAX-002	0.877	5.737	<0.001	Yes
NAPS vs. Reported	0.786	5.143	<0.001	Yes
NAPS vs. HFAX-049	0.720	4.301	0.002	Yes
HFAX-049 vs. HFAX-019	0.466	2.782	0.152	No
Reported vs. HFAX-019	0.400	2.616	0.215	No
HFAX-049 vs. HFAX-052	0.352	2.100	0.550	No
HFAX-002 vs. HFAX-019	0.309	2.022	0.595	No
Reported vs. HFAX-052	0.285	1.869	0.698	No
HFAX-028 vs. HFAX-019	0.279	1.824	0.711	No
HFAX-022 vs. HFAX-019	0.253	1.658	0.808	No
HFAX-002 vs. HFAX-052	0.195	1.275	0.962	No
HFAX-049 vs. HFAX-022	0.212	1.269	0.954	No
HFAX-049 vs. HFAX-028	0.187	1.118	0.977	No

HFAX-028 vs. HFAX-052	0.164	1.077	0.976	No
Reported vs. HFAX-022	0.146	0.958	0.985	No
HFAX-049 vs. HFAX-002	0.157	0.937	0.980	No
HFAX-022 vs. HFAX-052	0.139	0.911	0.974	No
Reported vs. HFAX-028	0.121	0.792	0.981	No
HFAX-052 vs. HFAX-019	0.114	0.747	0.975	No
Reported vs. HFAX-002	0.0907	0.594	0.983	No
HFAX-049 vs. Reported	0.0661	0.395	0.991	No
HFAX-002 vs. HFAX-022	0.0556	0.364	0.977	No
HFAX-002 vs. HFAX-028	0.0303	0.198	0.976	No
HFAX-028 vs. HFAX-022	0.0253	0.166	0.869	No

Pearson Product Moment Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-052	**HFAX-022**	**HFAX-002**	**HFAX-028**	**HFAX-049**	**NAPS**	**Reported**
HFAX-019	0.527 0.224 7	0.645 0.118 7	0.681 0.092 7	0.384 0.395 7	0.711 0.178 5	0.0605 0.897 7	0.429 0.337 7
HFAX-052		0.692 0.085 7	0.940 0.002 7	0.801 0.030 7	0.739 0.153 5	0.290 0.527 7	0.667 0.102 7
HFAX-022			0.838 0.018 7	0.906 0.005 7	0.881 0.048 5	0.604 0.151 7	0.843 0.017 7
HFAX-002				0.838 0.019 7	0.756 0.139 5	0.279 0.544 7	0.787 0.036 7
HFAX-028					0.964 0.008 5	0.584 0.169 7	0.850 0.015 7
HFAX-049						0.779 0.121 5	0.764 0.133 5
NAPS							0.363 0.424 7

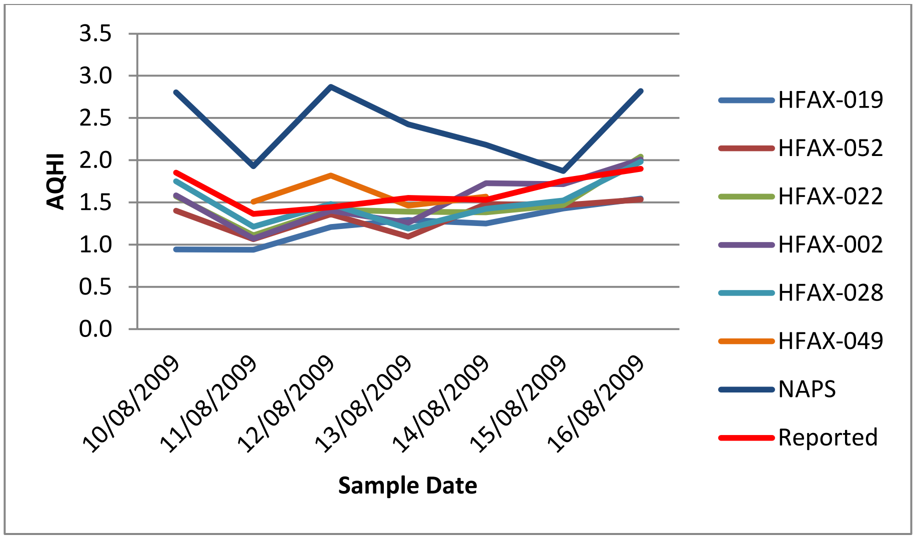

Figure 83. Time series of AQHI values for week six of the summer sampling campaign.

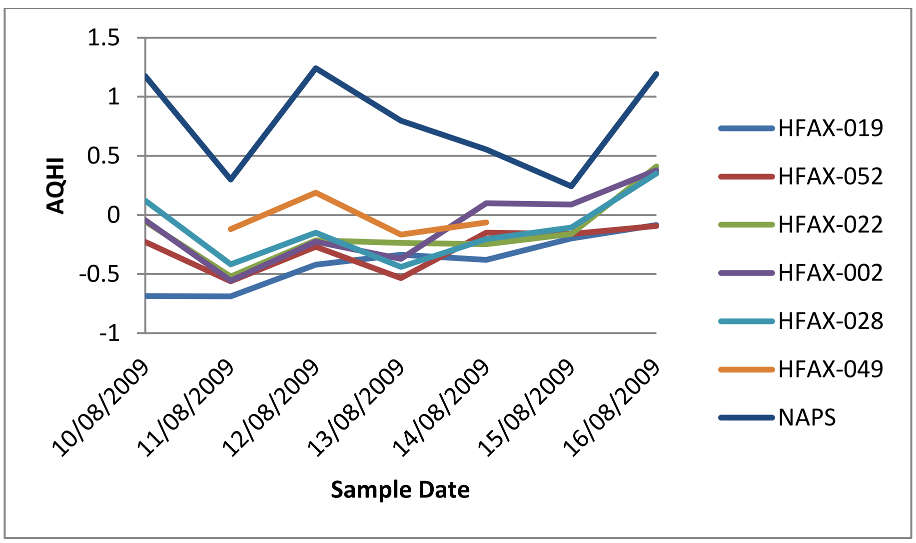

Figure 84. Time series of the deviations from normalized reported AQHI values for sample week six of the summer sampling campaign.

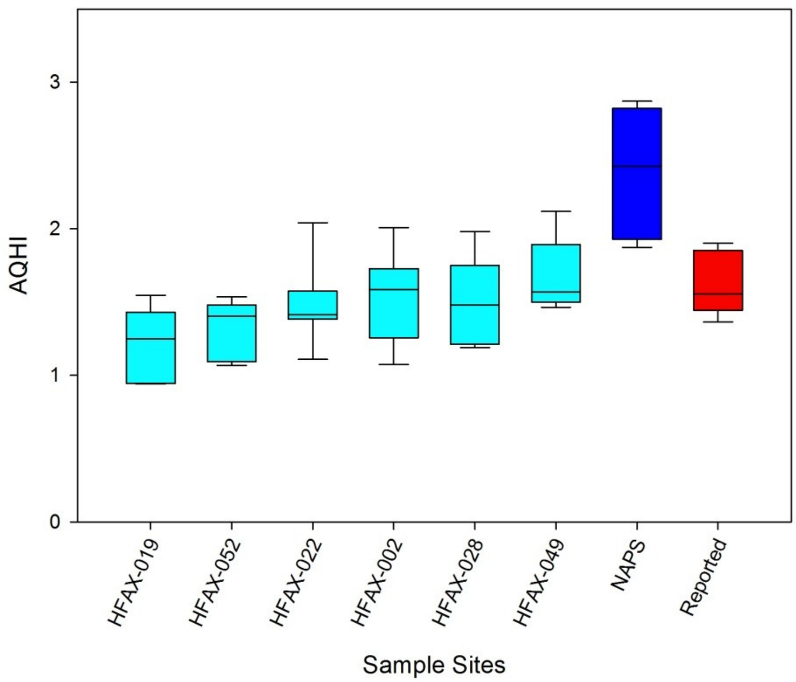

Figure 85. Box plot of AQHI values for sample week six of the summer sampling campaign.

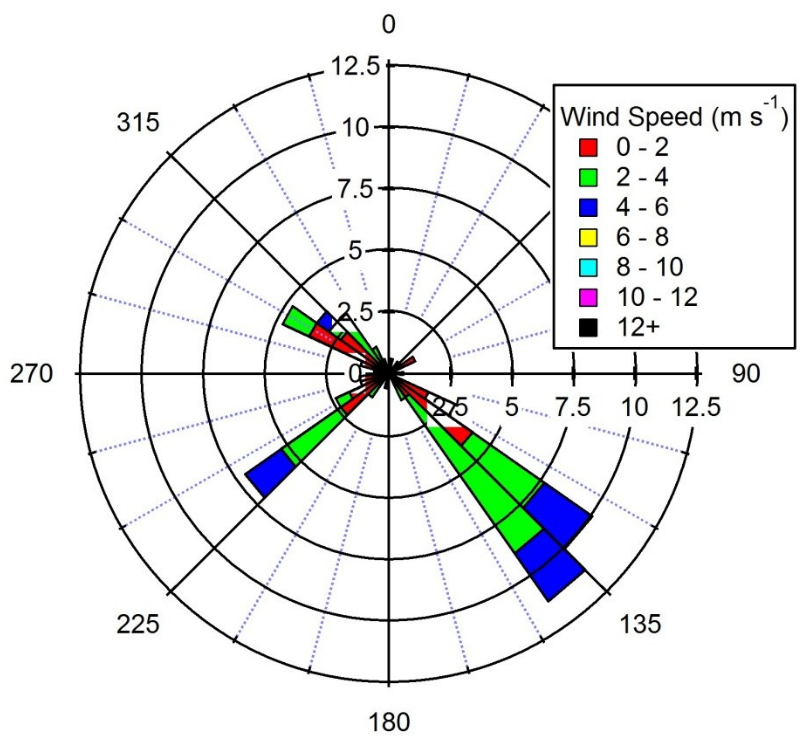

Figure 86. Wind rose of the wind conditions of week sex of the summer sampling campaign.

WEEK SEVEN, SUMMER SAMPLING CAMPAIGN (AUGUST 20 TO AUGUST 26, 2009)

Two days of AQHI data was lost during sampling during this week leaving five days of sampling for analysis with values ranges from 1.3 to 3.1 with a median values of 1.3. The time series analysis demonstrates a sharp drop in AQHI values from the first sampling day to the lower values of the remaining sample days (Figure. 21). Deviations from the reported AQHI values are low through the sample days. Wind conditions are predominantly from the South East (Figure. 24).

Statistically there was no variation between the sample sites, however there is only five sample points per site except for one sample site is missing an additional sample point, the Correlation coefficients where calculated by the Spearman Rank Order method, there were no significant relationships:

Normality Test (Shapiro-Wilk) Failed ($P < 0.050$)

Kruskal-Wallis One Way Analysis of Variance on Ranks

Group	**N**	**Missing**	**Median**	**25%**	**75%**
HFAX-0255		0	1.049	0.930	1.471
HFAX-0445		0	0.996	0.734	1.475
HFAX-0245		0	1.372	1.301	2.112
HFAX-0105		0	1.139	1.049	1.758
HFAX-0185		0	1.296	1.250	1.657
HFAX-0605		1	1.249	1.099	1.431
NAPS	5	0	1.765	1.523	2.481
Reported	5	0	1.184	1.047	2.373

H = 13.497 with 7 degrees of freedom. ($P = 0.061$)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.061)

Spearman Rank Order Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-044	**HFAX-024**	**HFAX-010**	**HFAX-018**	**HFAX-060**	**NAPS**	**Reported**
HFAX-025	0.800	0.500	0.900	0.900	-0.200	0.400	0.700
	0.133	0.450	0.083	0.083	0.917	0.517	0.233
	5	5	5	5	4	5	5
HFAX-044		0.900	0.900	0.500	0.200	0.600	0.300
		0.083	0.083	0.450	0.917	0.350	0.683
		5	5	5	4	5	5
HFAX-024			0.700	0.200	0.400	0.700	0.1000
			0.233	0.783	0.750	0.233	0.950
			5	5	4	5	5
HFAX-010				0.700	0.400	0.700	0.600
				0.233	0.750	0.233	0.350
				5	4	5	5
HFAX-018					-0.400	0.300	0.900
					0.750	0.683	0.083
					4	5	5
HFAX-060						1.000	0.000
						0.083	1.000
						4	4
NAPS							0.500
							0.450
							5

There are no significant relationships between any pair of variables in the correlation table (P > 0.050).

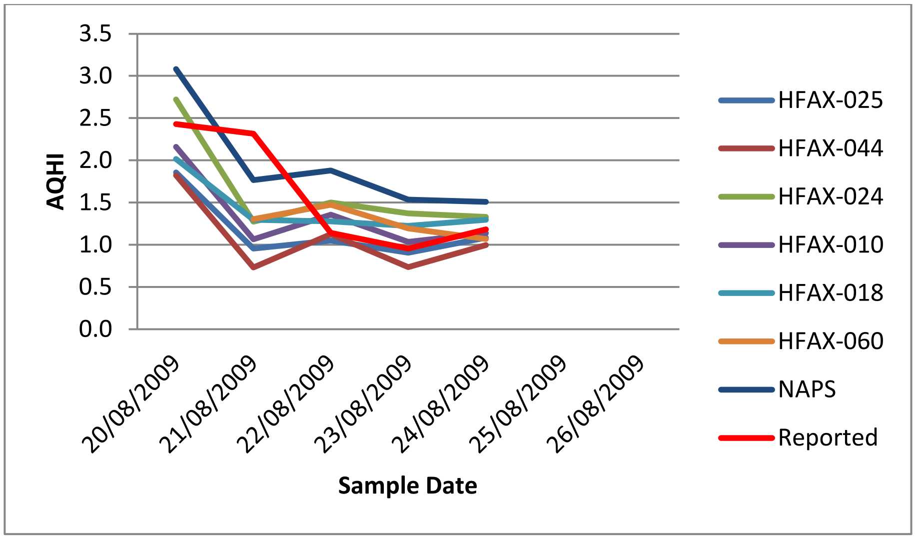

Figure 87. Time series of AQHI values for week seven of the summer sampling campaign.

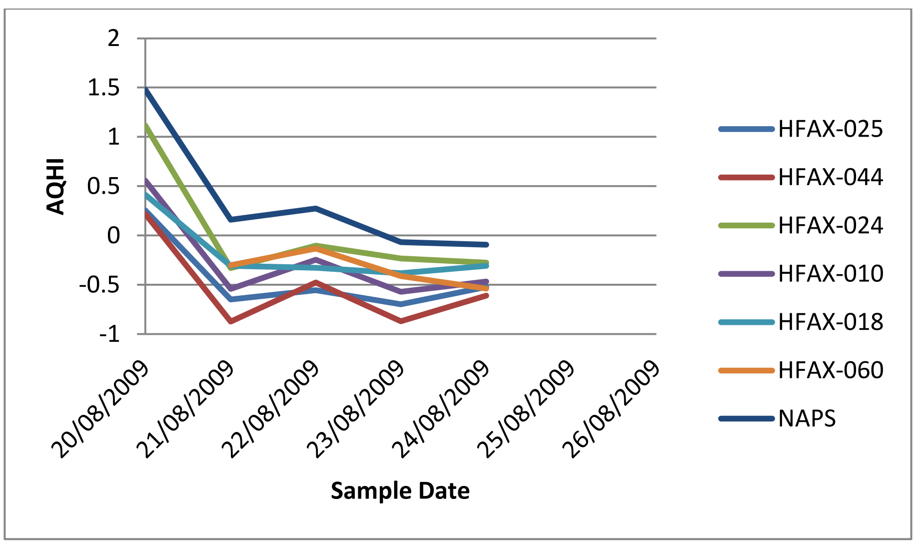

Figure 88. Deviations from the normalized reported AQHI values for week seven of the summer sampling campaign.

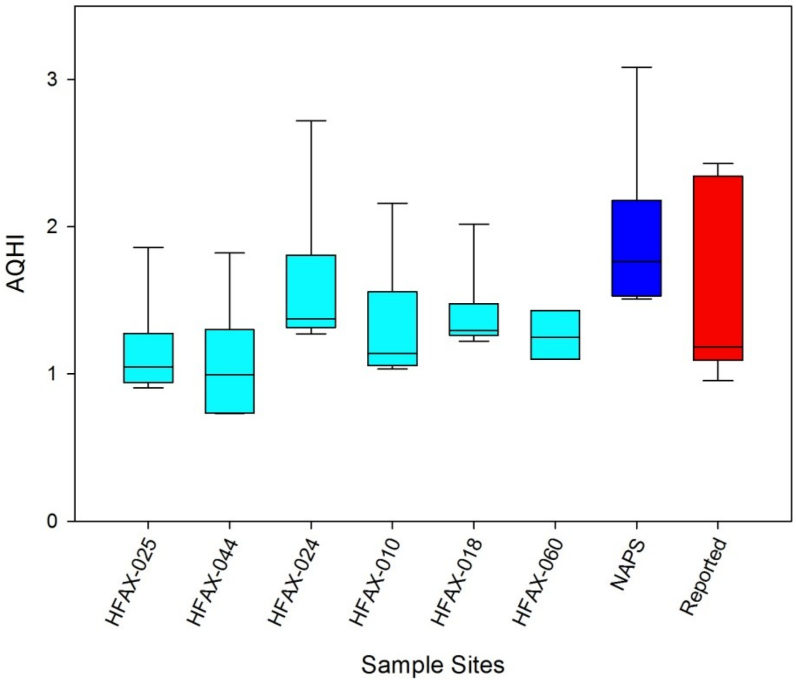

Figure 89. Box plot of the AQHI values for week seven of the summer sampling campaign..

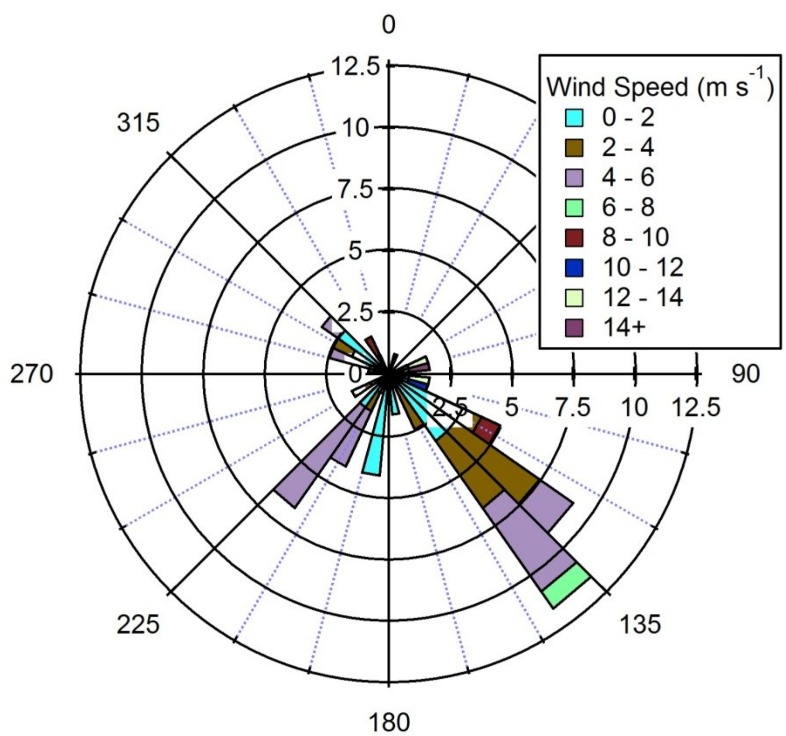

Figure 90. Wind rose of the wind conditions for week seven of the summer sampling campaign.

WEEK EIGHT, SUMMER SAMPLING CAMPAIGN (AUGUST 31 TO SEPTEMBER 6, 2009)

AQHI values for the sample week range from a minimum of 0.7 to a maximum of 2.2 with a median values 1.2 one sample site is missing three data points. The time series demonstrates a generally constant pattern across all sample sites (Figure. 25), and deviations reflect this pattern (Figure. 26). Wind conditions have two primary components, North West and south west (Figure. 28).

The AQHI data was analyzed using ANOVA and the Holm-Sidak method with one sample site showing a significant difference from the reported AQHI value, the Pearson Product Moment method was used for correlation coefficients:

Normality Test (Shapiro-Wilk) Passed (P = 0.550)

Equal Variance Test: Passed (P = 0.466)

Group Name	**N**	**Missing**	**Mean**	**Std Dev**	**SEM**
HFAX-055	7	0	1.061	0.290	0.109
HFAX-059	7	0	1.307	0.266	0.101
HFAX-056	4	0	0.748	0.0435	0.0217
HFAX-034	7	0	1.020	0.226	0.0854
HFAX-027	7	0	1.138	0.296	0.112
NAPS	7	0	1.569	0.357	0.135
Reported	7	0	1.345	0.327	0.124

Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Between Groups	6	2.389	0.398	4.894	<0.001
Residual	39	3.173	0.0814		
Total	45	5.562			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 0.945

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):
Overall significance level = 0.05

Comparisons for factor:

Comparison	**Diff of Means**	**t**	**P**	**P<0.050**
NAPS vs. HFAX-056	0.822	4.595	<0.001	Yes
NAPS vs. HFAX-034	0.549	3.603	0.017	Yes
Reported vs. HFAX-056	0.597	3.340	0.035	Yes
NAPS vs. HFAX-055	0.508	3.333	0.033	Yes
HFAX-059 vs. HFAX-056	0.559	3.129	0.055	No
NAPS vs. HFAX-027	0.432	2.832	0.110	No
HFAX-027 vs. HFAX-056	0.390	2.180	0.417	No
Reported vs. HFAX-034	0.325	2.131	0.431	No
HFAX-059 vs. HFAX-034	0.287	1.884	0.594	No
Reported vs. HFAX-055	0.284	1.861	0.583	No
HFAX-055 vs. HFAX-056	0.313	1.753	0.635	No
NAPS vs. HFAX-059	0.262	1.719	0.625	No
HFAX-059 vs. HFAX-055	0.246	1.614	0.665	No
HFAX-034 vs. HFAX-056	0.272	1.523	0.689	No
NAPS vs. Reported	0.224	1.472	0.677	No
Reported vs. HFAX-027	0.207	1.360	0.700	No
HFAX-059 vs. HFAX-027	0.170	1.113	0.796	No
HFAX-027 vs. HFAX-034	0.118	0.771	0.905	No
HFAX-027 vs. HFAX-055	0.0764	0.501	0.945	No
HFAX-055 vs. HFAX-034	0.0411	0.270	0.955	No
Reported vs. HFAX-059	0.0377	0.247	0.806	No

Pearson Product Moment Correlation

Cell Contents:
Correlation Coefficient
P Value
Number of Samples

	HFAX-059	HFAX-056	HFAX-034	HFAX-027	NAPS	Reported
HFAX-055	0.203	-0.319	0.797	0.662	0.649	0.694
	0.662	0.681	0.032	0.105	0.115	0.083
	7	4	7	7	7	7
HFAX-059		0.447	0.352	0.724	0.514	0.558
		0.553	0.439	0.066	0.238	0.193
		4	7	7	7	7
HFAX-056			-0.125	0.00288	-0.506	0.513
			0.875	0.997	0.494	0.487
			4	4	4	4
HFAX-034				0.841	0.748	0.425
				0.018	0.053	0.342
				7	7	7
HFAX-027					0.909	0.609
					0.005	0.147
					7	7
NAPS						0.453
						0.307
						7

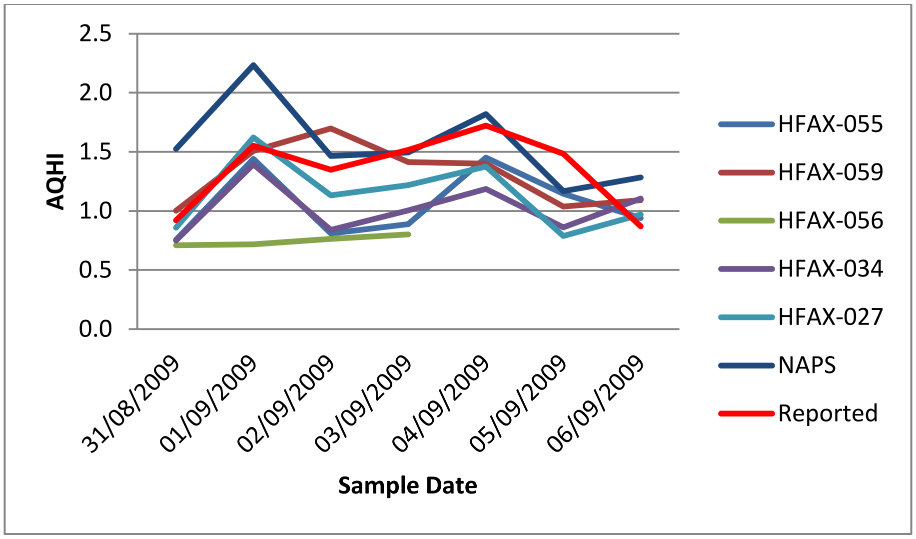

Figure 91. Time series of the AQHI values for week eight of the summer sampling campaign.

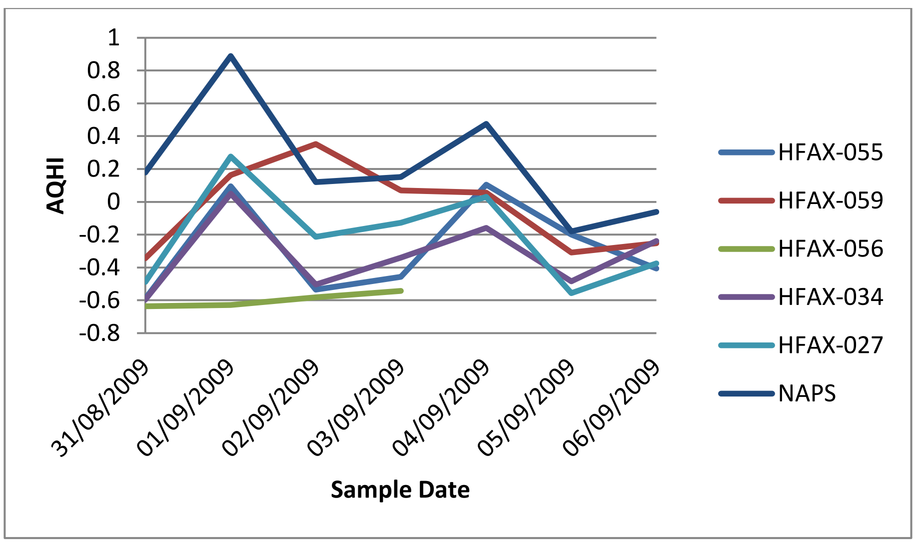

Figure 92. Deviations from the normalized reported AQHI values for this sample week.

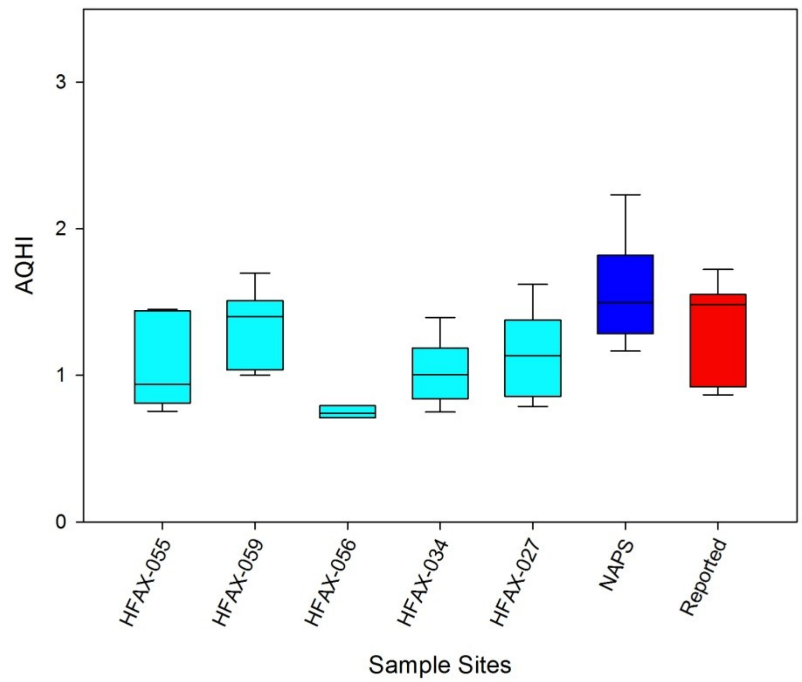

Figure 93. Box plot of the reported AQHI values for week eight of the summer sampling campaign.

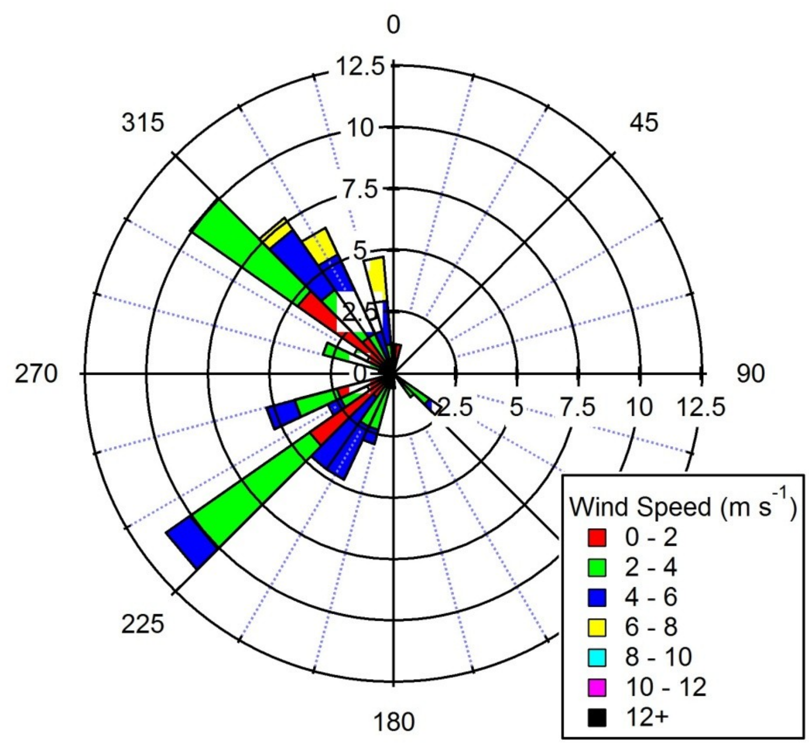

Figure 94. Wind rose plot of wind conditions for sample week eight of the summer sampling campaign.

Week nine, summer sampling campaign (September 10 to September 16. 2009)

AQHI values ranged from a minimum of 0.7 to a maximum of 1.8 with a median of 1.1. Deviation from the reported AQHI is minimal (Figure. 30) with the time series analysis showing mixed patterns through the week (Figure. 29). Dominant wind is from the South East with the a secondary component from the south west (Figure. 31).

The data from this sample week satisfies both the normality and equal variance and is tested using ANOVA and the Holm-Sidak method for multiple comparison which identified that two of the sample sites are significantly different from the reported AQHI. The Pearson Product Moment method was used to calculate correlation coefficients:

Normality Test (Shapiro-Wilk) Passed (P = 0.724)

Equal Variance Test: Passed (P = 0.483)

Group Name	N	Missing	Mean	Std Dev	SEM
HFAX-043	7	0	0.957	0.117	0.0444
HFAX-008	7	0	1.092	0.0982	0.0371
HFAX-051	7	0	1.012	0.134	0.0506
HFAX-062	7	0	1.237	0.142	0.0537
HFAX-061	7	0	1.012	0.196	0.0740
HFAX-047	7	0	0.812	0.0622	0.0235
NAPS	7	0	1.616	0.198	0.0748
Reported	7	0	1.229	0.204	0.0769

Source of Variation	DF	SS	MS	F	P
Between Groups	7	2.920	0.417	18.116	<0.001
Residual	48	1.105	0.0230		

Total 55 4.025

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):
Overall significance level = 0.05

Comparisons for factor:

Comparison	**Diff of Means**	**t**	**P**	**P<0.050**
NAPS vs. HFAX-047	0.804	9.914	<0.001	Yes
NAPS vs. HFAX-043	0.659	8.125	<0.001	Yes
NAPS vs. HFAX-051	0.605	7.457	<0.001	Yes
NAPS vs. HFAX-061	0.604	7.447	<0.001	Yes
NAPS vs. HFAX-008	0.524	6.462	<0.001	Yes
HFAX-062 vs. HFAX-047	0.425	5.234	<0.001	Yes
Reported vs. HFAX-047	0.417	5.136	<0.001	Yes
NAPS vs. Reported	0.388	4.778	<0.001	Yes
NAPS vs. HFAX-062	0.380	4.680	<0.001	Yes
HFAX-008 vs. HFAX-047	0.280	3.451	0.022	Yes
HFAX-062 vs. HFAX-043	0.279	3.445	0.021	Yes
Reported vs. HFAX-043	0.271	3.347	0.027	Yes
HFAX-062 vs. HFAX-051	0.225	2.777	0.118	No
HFAX-062 vs. HFAX-061	0.224	2.767	0.114	No
Reported vs. HFAX-051	0.217	2.679	0.132	No
Reported vs. HFAX-061	0.217	2.669	0.126	No
HFAX-061 vs. HFAX-047	0.200	2.466	0.189	No
HFAX-051 vs. HFAX-047	0.199	2.456	0.178	No
HFAX-043 vs. HFAX-047	0.145	1.789	0.565	No
HFAX-062 vs. HFAX-008	0.145	1.782	0.532	No

Reported vs. HFAX-008	0.137	1.684	0.564	No
HFAX-008 vs. HFAX-043	0.135	1.662	0.533	No
HFAX-008 vs. HFAX-051	0.0807	0.995	0.905	No
HFAX-008 vs. HFAX-061	0.0799	0.985	0.865	No
HFAX-061 vs. HFAX-043	0.0549	0.677	0.938	No
HFAX-051 vs. HFAX-043	0.0541	0.667	0.881	No
HFAX-062 vs. Reported	0.00796	0.0982	0.994	No
HFAX-061 vs. HFAX-051	0.000815	0.0100	0.992	No

Pearson Product Moment Correlation

Cell Contents:

Correlation Coefficient

P Value

Number of Samples

	HFAX-008	HFAX-051	HFAX-062	HFAX-061	HFAX-047	NAPS	Reported
HFAX-043	0.779	-0.514	-0.327	-0.515	0.527	0.246	-0.131
	0.039	0.238	0.473	0.237	0.224	0.594	0.779
	7	7	7	7	7	7	7
HFAX-008		-0.346	-0.494	-0.344	0.364	0.408	0.164
		0.447	0.260	0.450	0.422	0.363	0.726
		7	7	7	7	7	7
HFAX-051			0.681	0.927	-0.104	0.423	-0.266
			0.092	0.003	0.825	0.344	0.564
			7	7	7	7	7
HFAX-062				0.805	0.418	0.517	-0.246
				0.029	0.351	0.235	0.595
				7	7	7	7
HFAX-061					0.181	0.621	-0.294
					0.697	0.137	0.522
					7	7	7
HFAX-047						0.776	-0.247
						0.040	0.593
						7	7
NAPS							-0.238
							0.608
							7

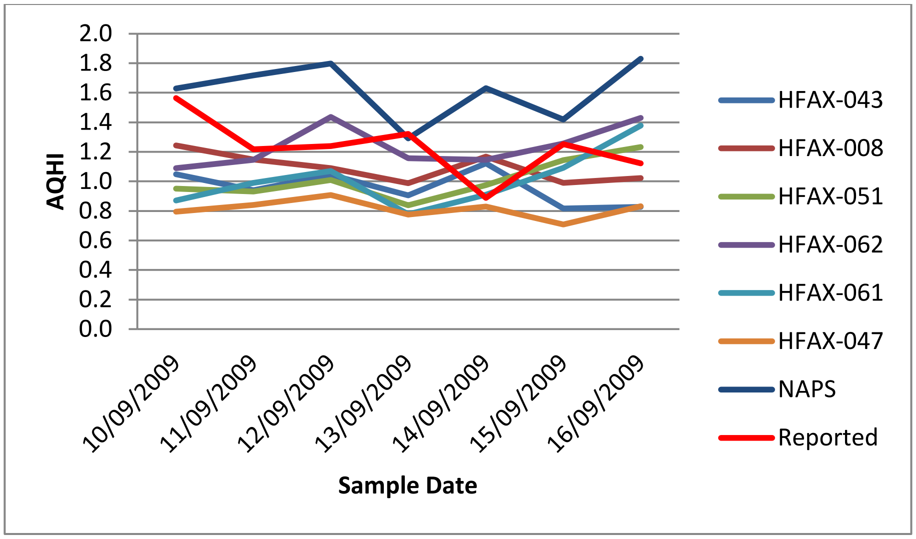

Figure 95. Time series of AQHI values for sample week nine of the summer sampling campaign

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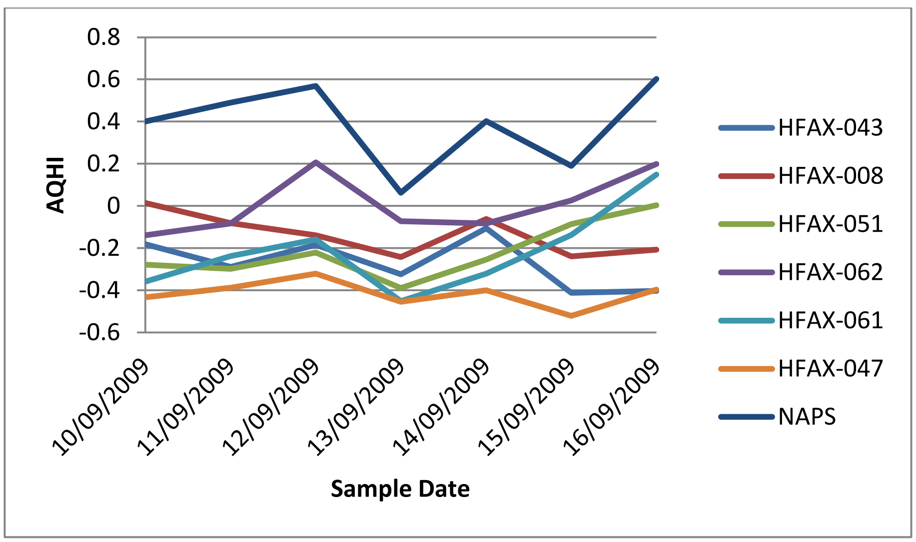

Figure 96. Time series of deviations from the normalized reported AQHI values for week nine of the summer sampling campaign.

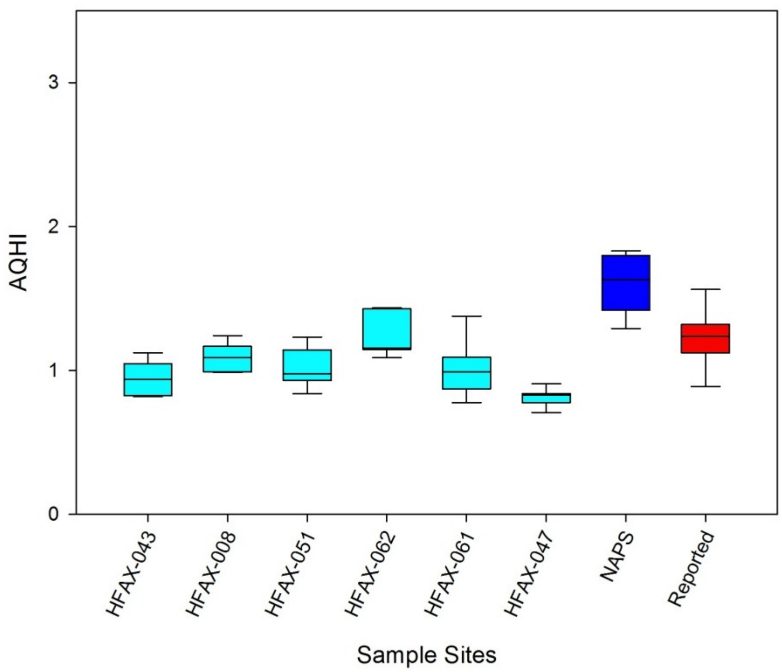

Figure 97. Box plot of AQHI values for the final week of the summer sampling campaign.

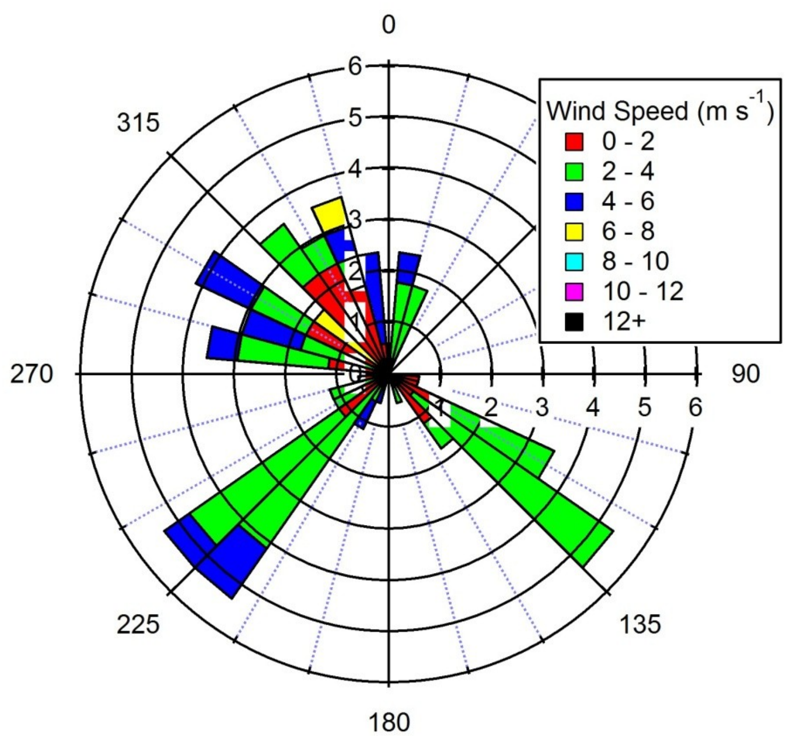

Figure 98. Wind rose plot of the wind conditions for week nine of the summer sampling campaign

APPENDIX C: AQHI CATEGORIES AND MESSAGES

This appendix demonstrates the AQHI ranking system and the health messages that correspond to each category.

Environment Canada Environnement Canada Canada

Home > About the AQHI > AQHI Categories and Messages

AQHI Categories and Messages

The Air Quality Health Index uses a scale to show the health risk associated with the air pollution we breathe.

The following table provides the health messages for 'at risk' individuals and the general public for each of the AQHI Health Risk Categories.

Health Risk	Air Quality Health Index	Health Messages	
		At Risk Population*	**General Population**
Low	**1 - 3**	**Enjoy** your usual outdoor activities.	**Ideal** air quality for outdoor activities.
Moderate	**4 - 6**	**Consider reducing** or rescheduling strenuous activities outdoors if you are experiencing symptoms.	**No need to modify** your usual outdoor activities unless you experience symptoms such as coughing and throat irritation.
High	**7 - 10**	**Reduce** or reschedule strenuous activities outdoors. Children and the elderly should also take it easy.	**Consider reducing** or rescheduling strenuous activities outdoors if you experience symptoms such as coughing and throat irritation.
Very High	**Above 10**	**Avoid** strenuous activities outdoors. Children and the elderly should also avoid outdoor physical exertion.	**Reduce** or reschedule strenuous activities outdoors, especially if you experience symptoms such as coughing and throat irritation.

* People with heart or breathing problems are at greater risk. Follow your doctor's usual advice about exercising and managing your condition.

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